BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF MECHANICAL ENGINEERING
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ÚSTAV STROJÍRENSKÉ TECHNOLOGIE

IMPLEMENTATION OF AUTOMATION ELEMENTS WITHIN MACHINING PROCESSES IN POCLAIN HYDRAULICS S.R.O.

IMPLEMENTACE PRVKŮ AUTOMATIZACE DO VÝROBNÍHO PROCESU V POCLAIN HYDRAULICS S.R.O.

MASTER'S THESIS
DIPLOMOVÁ PRÁCE

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Zadání diplomové práce

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Implementace prvků automatizace do výrobního procesu v Poclain Hydraulics s.r.o.

Stručná charakteristika problematiky úkolu:

Zanalyzovat aktuální způsob výroby drah pro hydraulické motory a navrhnout jeho optimalizaci. Nastudovat možnosti automatizace v společnosti a udělat průzkum prvků automatizace dostupných na trhu. Zpracovat technicko–ekonomickou analýzu a komunikovat výsledky s dalšími závody Poclain Hydraulics s.r.o.

Cíle diplomové práce:

1. Posouzení současných obráběcích procesů součástí hydraulických motorů (SE vaček) a optimalizace těchto procesů.
2. Identifikace a zavedení prvků automatizace do současných obráběcích procesů.
3. Ekonomické zhodnocení zavedených opatření.
4. Diskuze výsledků s jinými výrobními divizemi společnosti Poclain Hydraulics Group.
5. Závěry

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ABSTRAKT

Úvod

Táto práca bola vytvorená v spolupráci s firmou Poclain Hydraulics s.r.o. (ďalej iba ako „PH“), ktorá je svetovým výrobcom hydrostatického pohonu. Táto pôvodom francúzska spoločnosť sa špecializuje najmä na výrobu čerpadiel, hydraulických motorov a ventilov. Všetky informácie a dáta boli spracované v závode v Brne v Českej Republike. Táto pobočka je zameraná na výrobu vnútorných súčiastok hydraulických motorov akými sú napríklad rotor alebo dráha.

Práca sa zaoberá možnosťami automatizácie a robotizácie výrobnej linky dráh pre motory typu „MS“. Dráha je statická súčiastka motora, ktorá je neustále mechanicky namáhaná rotujúcimi piestami pri zvýšenej teplote. Jedná sa o kritickú súčiastku ktorá priamo ovplyvňuje životnosť motora, ako aj jeho pracovnú efektivitu. Závod v Brne je jediným závodom spoločnosti v Európe v ktorom sa vyrábajú dráhy pre motory tohto typu . Zároveň sa jedná o závod ktorý dodáva časť týchto dráh aj pre trh v Ázii, konkrétne v Indii. Je preto nevyhnutné aby bol zabezpečený minimálny počet zmätkov a vysoká produktivita.

Cieľom práce je analýza aktuálnej výroby v závode so zameraním na výrobnú bunku tzv. SE dráh, zhrnutie možností automatizácie a robotizácie, návrhy automatizovaných pracovísk a ekonomická analýza riešení. Najprv sú uvedené všeobecné pravidlá a obmedzenia, ktoré treba dodržiavať v rámci celej skupiny PH všade po svete. Následne sú navrhnuté viaceré možnosti automatizácie ktoré obsahujú analýzu pracovného toku, popis výrobného procesu spolu s vizualizáciou, porovnanie s aktuálnou situáciou a ekonomický dopad.

TEORETICKÝ ROZBOR

Hydraulické motory

Hydraulický motor je mechanický aktuátor ktorý premieňa potenciálnu hydraulickú energiu na mechanickú otáčavú energiu. Hydraulické motory môžu byť rozdelené na vysoko rýchlostné a nízko rýchlostné motory. V závislosti na konštrukcii motorov sa ďalej rozdeľujú na zubové, lopatkové alebo piestové. Všetky druhy pracujú na rovnakom princípe – rozdiel tlaku na dvoch stranách aktuátora ktorý spolu s presným plánovaním zabezpečuje rotáciu výstupného hriadeľa [1].

Spoločnosť PH je zameraná na výrobu piestových hydraulických motorov, konkrétne na radiálny druh týchto motorov. Radiálne piestové motory fungujú na princípe vysúvania a zasúvania radiálne uložených piestov striedaním tlaku prívodnej kvapaliny. Piesty sú upevnené na cylindri ktorý je priamo spojený s výstupným hriadeľom. Vysúvaním piestov dochádza ku ich kontaktu s dráhou, ktorej geometria zabezpečuje že reakčné sily rotujú cylinder do strany. Výhodou takýchto motorov je možnosť plynulej zmeny smeru rotácie. Motory vyrábané v spoločnosti sú koncentrické čo zabezpečuje dokonalé vyrovnanie radiálne pôsobiacich síl, vďaka čomu môžu veľmi rýchlo a hladko naštartovať aj pracovať tak aj pri nízkych otáčkach.

Výhodou motorov typu MS oproti konkurencii sú vysoká efektivita a žiadne straty spôsobené prevodmi. Jedná sa o nízko-rýchlostný motor s malou hybnosťou, jednoduchým systémom tzv. *stop&go* a konštantným krútiacim momentom. Tento typ motorov je najčastejšie využívaný v agrikultúrnom priemysle, stavebníctve, lesníctve alebo iných oblastiach ktoré využívajú ťažké pohyblivé stroje [3].

Automatizácia

Automatizácia je nevyhnutnou súčasťou modernej priemyselnej výroby a poskytuje možnosť zvýšenia kapacity výroby bez zníženia výslednej kvality výrobku. Je to fáza technickej evolúcie, ktorá znamená výrobu bez priameho zásahu človeka, avšak stále pod jeho dohľadom. Automatizácia sa začala rozvíjať začiatkom 20. storočia s vynálezom moderných počítacích systémov. Definíciou automatizácie je používanie rôznych samočinných technologických prvkov, ktorých ovládanie je striktne stanovené dopredu pripraveným programom. Vo vyšších formách automatizácie sa používajú senzory, ktoré aktívne kontrolujú aktuálnu situáciu a sú schopné výrobne proces jemne upraviť aby spĺňal stanovené podmienky bez nutnosti nápravného zásahu človekom [6].

Ľudský zásah do automatizovaného procesu je najčastejšie nevyhnutný pri vykonávaní sekundárnych operácii ktoré by boli pre automatizáciu moc komplikované, alebo zbytočne finančne náročné. Príkladom môže byť uchopovanie voľne ležiacej súčiastky a jej presné zakladanie do stroja. Na takéto situácie sa používa kombinácia dopravníka alebo iného systému ktorý súčiastku dopraví do presne určeného miesta v kombinácii s 2D alebo 3D víziou [6].

Výrobný systém

Výrobný systém je akákoľvek výrobná jednotka, ktorá môže byť považovaná za istým spôsobom izolovanú, ako napríklad dielňa alebo celý výrobný závod, v závislosti ako na uvažovaných podmienkach. Za základnú jednotku výrobného systému sú vo všeobecnosti považované pracoviská. Obrábacie centrum spolu so zásobníkom nástrojov alebo aj automatickým výmenníkom paliet je považovaný za jedno pracovisko. Ak sú takéto pracoviská a prevoz materiálu medzi nimi automatizované, nazýva sa to automatickým výrobným systémom. Tie sú rozdelené do dvoch veľkých skupín – pevné a flexibilné. Pevné automatické výrobné pracoviská sú charakteristické veľmi veľkou produktivitou avšak bez možnosti vyrábať viaceré druhy produktov. Flexibilné automatické výrobné pracoviská majú naopak nižšie výrobné tempo ale zároveň dovoľujú výrobu rôznych veľkostí a typov daného produktu [5].

Flexibilný výrobný systém

Flexibilná výrobná jednotka sa skladá z jedného výrobného stroja ktorý je schopný aspoň poloautomatického chodu. Flexibilná výrobná bunka sa skladá z dvoch a viacerých výrobných strojov ktoré sú plne kontrolované počítačom. Flexibilný výrobný systém sa skladá z dvoch a viacerých výrobných buniek ktoré sú prepojené automatizovaným transportným systémom. Jedná sa teda o počítačom kontrolovaný integrovaný komplex CNC pracovísk s minimálnym ľudským zásahom a malým množstvom potrebných nastavení pre výrobu predom stanovených súčiastok. Takýto systém umožňuje vyrábať rôzne produkty v malých alebo stredných sériách, je však výrazne finančne nákladnejší ako pevný automatizovaný výrobný systém.

Výrobné systémy sa bežne vylepšujú z manuálnych na automatizované postupne s ohľadom na dostupné financie. Je preto dôležité, aby každý krok postupnej automatizácie dovoľoval chod výrobného systému [5].

Robotizácia

Roboty sa veľmi rýchlo vyvinuli z teórie k ich aplikácii začiatkom roku 1970, najmä z dôvodu potreby zvýšiť produktivitu a kvalitu výroby. Zvýšená produktivita je najväčším benefitom priemyselných robotov, keďže roboty môžu pracovať v tzv. režime 24/7 a to za zlomok ceny neautomatizovanej výrobnej linky. Roboty nepodliehajú únave, neopatrnosti alebo ich emóciám čo prispieva k zníženiu rizík a úrazov na pracovisku. Vďaka tomu je ich aplikácia vhodná taktiež pre prácu v ťažkých podmienkach akými sú zvýšená teplota, znečistené ovzdušie alebo manipulácia s toxickými látkami. Popri zvýšení produktivity k ich výhodám patria rýchlosť a presnosť pohybu a najmä nahradenie fyzicky náročných činností operátorov [8].

Pri vyhodnocovaní potenciálnej aplikácie robotov, je potrebné brať do úvahy elementy ako cyklový čas, tvarové a geometrické tolerancie súčiastky, užitočné zaťaženie, dosah, pamäť, ľudský faktor a tak isto cena a údržba. Priemyselný robot je podľa normy ISO 8373:1994 definovaný ako automaticky riadený, programovateľný viacúčelový manipulátor pre činnosť v troch alebo viacerých osách. Manipulátor je stroj s dvoj pozičnou samo riadiacou pohybovou jednotkou a navádzaním pre automatickú manipuláciu so súčiastkami. Roboty môžu byť vybavené rôznymi obrábacími nástrojmi, chápadlami alebo inými nástrojmi pre manipuláciu, technologické alebo montážne operácie [8].

Z mechanického hľadiska sú roboty zložené z ramien a kĺbov. Kĺby slúžia pre zaručenie pohyblivosti a ramená slúžia ako pevné spojenie medzi nimi. V súčasnej dobe má väčšina moderných robotov 6 stupňov pohyblivosti, okrem menších a jednoúčelových typov. Koncový efektor je samostatná časť robota, ktorá slúži na uchytenie objektu pomocou chápadla. Je to kľúčová časť robota ktorá priamo ovplyvňuje pozíciu a orientáciu súčiastky, v závislosti na funkcii sa rozdeľuje na chápadlá, hlavice, integrované efektory a nástroje [9].

Riadiaci systém robota číta informácie z pamäte riadiaceho počítača a tak isto aj informácie zo senzorov, na základe čoho je pohyb robota navigovaný. Navigácia robota je komplexný systém mikroprocesorov pracujúcich v súlade s viacúrovňovou metódou ktorá spracováva viacero operácii naraz. Súčasťou priemyselných robotov je aj ovládací panel, pomocou ktorého je operátor schopný manuálne ovládať prácu robota a korigovať ju [9].

ANALÝZA POŽIADAVKOV PRE AUTOMATIZÁCIU A EXISTUJÚCE RIEŠENIA

Aktuálny výrobný proces

Momentálne používaný výrobný proces pozostáva z nákupu polotovarov od externých dodávateľov a následného obrábania na požadovaný tvar a rozmer. Jedná sa o sústruženie, frézovanie, tepelné spracovanie, brúsenie a honovanie a tieto operácie sú rozdelené medzi dve výrobné bunky. Plánovaná automatizácia sa týka iba jednej bunky, preto brúsenie krivky ani honovanie, ktoré sú súčasťou druhej bunky nebudú v tejto práci rozoberané. Komplexnosť riešenia automatizácie je umocnená tým, že na rovnakých strojoch sú paralelne vyrábané rôzne veľkosti dráh. To znamená, že dané výrobné stroje musia byť pripravené na rýchlu zmenu výrobku a teda musia byť ľahko nastaviteľné aby bol čas prestoja čo najkratší. Stroje sú aktuálne optimalizované na výrobu 4 rôznych veľkosti dráh.

Sústruženie

Prvou operáciou je sústruženie zložené z dvoch obrábacích cyklov. Dráha je dopravená na určenú pozíciu pomocou dopravníka, ktorý je manuálne nakladaný. Je používaný dvojvretenový vertikálny sústruh, takže vretená vykonávajú rôzne cykly paralelne. Jedná sa o pomerne jednoduché pozdĺžne a radiálne sústruženie dráhy, ktorá je po obrobení vyložená na druhý dopravník. Následne operátor ofúka dráhu od otrepov stlačeným vzduchom a umiestni ju do gravírovacieho zariadenia. Každý kus je označený vlastným QR kódom špecifikujúcim typ dráhy, pričom sa jedná o značenie mikroúderom. Je nutné uviesť, že každý 10 obrobený kus je kontrolovaný operátorom, pri tejto kontrole sa dohliada na presnosť obrábaných rozmerov a teda vonkajší priemer dráhy a hrúbka dráhy. Ďalej je nutné kontrolovať tieto charakteristiky pri každej výmene nástroja, ktorý je spojený s ich obrábaním. Na každom prvom a poslednom kuse v sérii sú kontrolované aj ďalšie dve charakteristiky a to rovnobežnosť a skosenie hrán. Následne je dráha manuálne uložená do KLT prepraviek ktoré slúžia ako dočasný odkladací priestor pred ďalšou operáciou.

Frézovanie

Nasleduje frézovanie dráh, na čo sú používané dve identické horizontálne frézovacie centrá. Jedná sa o tzv. dvojblokové frézky to znamená, že frézka má otočný stôl rozdelený na dve časti z ktorých vždy jedna časť je v obrábacom priestore zatiaľ čo k druhej má operátor prístup a môže manipulovať s obrobkami. Každá časť stola má naviac ďalšiu horizontálnu otočnú dosku, čo znamená že každý stroj má teoreticky k dispozícii 8 rôznych upínacích dosiek. Každá doska môže byť prispôsobená na inú veľkosť alebo iný typ dráhy čo výrazne zvyšuje flexibilitu stroja. Dráhy sú manuálne upínané na špeciálnu upínaciu dosku, ktorá je navrhnutá tak aby bola každá dráha upnutá s presnosťou 0,01 mm. Pred upnutím je doska ofúkaná stlačeným vzduchom aby sa predišlo výrobným zmätkom spôsobeným otrepmi ktoré svojou prítomnosťou môžu vykriviť dráhy z definovanej polohy. Oba stroje pracujú paralelne a v závislosti na veľkosti dráhy sú na každú dosku upínané až 4 kusy dráh, ktoré sú obrábané jedným vretenom v rovnakom obrábacom cykle. Po skončení obrábacieho cyklu sú dráhy ofúkané stlačeným vzduchom, vyložené na stôl, obrúsené brúsnym kameňom a uložené buď to KLT prepraviek alebo na paletu v ktorej budú pokračovať na tepelné spracovanie. Tak isto ako pri sústružení prebieha pravidelná kontrola rozmerov v tomto prípade každého 8. kusu alebo pri výmene nástroja ktorým je daný povrch obrábaný. Posuvným meradlom sa kontrolujú ofrézované vnútorné priemery krivky a valčekovým kalibrom sa kontrolujú vyvŕtané diery. Na každom prvom a poslednom kuse v sérii sú kontrolované rozmery všetkých obrábaných povrchov.

Zvyšné operácie

Po frézovaní sú obrobené dráhy ukladané do špeciálnych prípravkov na tepelné spracovanie. Jedná sa o kovové palety na ktoré sú dráhy navliekané okolo stredových tyčí do stĺpcov. Na spodok stĺpca a následne medzi každé 2 kusy dráh sú uložené stredové prípravky pre zachovanie rovnomernosti vlastností dráh po tepelnom spracovaní. Po naplnení je paleta operátormi zavezená k zdvíhaciemu zariadeniu, od tohto bodu je proces tepelného spracovania úplne automatizovaný. V porovnaní s ostatnými operáciami bunky sa jedná o najdlhší proces ktorý trvá od 5 do 9 hodín a naraz sa tepelne spracovávajú dve plné palety. Celá operácia je kontrolovaná určenými zamestnancami ktorí priebežne dohliadajú na prebiehajúce fázy a funkcie technologického zariadenia. Po dokončení je paleta dopravená k zdvíhaciemu zariadeniu ktorým bola naložená a po ochladení sú dráhy vyložené operátorom do KLT prepraviek. Rošt palety, stredové tyče a stredové prípravky sú uložené do odkladacieho priestoru pre ďalšie použitie.

Poslednou operáciou v tejto výrobnej bunke je brúsenie na plocho, ktoré je vykonávané na dvoch horizontálnych vodových brúskach. Dráhy sú upínané po 5-8 kusov na magnetickú dosku a následne axiálne brúsené za neustáleho chladenia chladiacou kvapalinou. Po obrúsení je potrebné dráhy odmagnetizovať a uložiť do KLT prepraviek v ktorých sú presunuté k druhej výrobnej bunke určenej na super-dokončovacie operácie. Tak isto ako pri predchádzajúcich operáciách je vykonávaná pravidelná kontrola kusov. Na každom piatom kuse sa kontroluje rovinnosť, rovnobežnosť, výška dráhy, jej priemer a skosenie navŕtaných dier. Vždy na prvom a poslednom kuse v sérii sa kontroluje aj drsnosť povrchu z oboch strán dráhy.

Pri plánovaní usporiadania celej výrobnej bunky je potrebné brať do úvahy všetky faktory s ktorými interaguje a ktoré na ňu vplývajú. Jedná sa napríklad o pracovné prostredie, IT sieť, údržba alebo operátor. Každý z týchto faktorov vnáša do plánovania bunky určité obmedzenia, ktoré môžu byť viac alebo menej flexibilné. Je preto potrebné, vytvoriť súhrn vplyvov a možností ich modifikácií ktorý bude použitý pri plánovaní optimálneho riešenia.

IDENTIFIKÁCIA EXISTUJÚCICH PRVKOV AUTOMATIZÁCIE

Automatizácia výroby je aktuálne veľkým projektom v spoločnosti PH, ktorý prebieha vo viacerých pobočkách po celom svete. V rámci zachovania objektivity je bežným postupom kontaktovanie viacerých spoločností špecializovaných na automatizáciu a robotizáciu. V tomto prípade boli vybratí štyria výrobcovia robotov a to FANUC, ABB, KUKA a YASKAWA. S obchodným zástupcom každej spoločnosti bolo dohodnuté osobné stretnutie priamo v závode PH v Brne. Počas tohto stretnutia mali spoločnosti možnosť vidieť aktuálnu výrobnú linku a boli prediskutované požiadavky PH. Každá z firiem má rozdielnu stratégiu, niektoré z nich dodávajú všetko od softvéru, rôznych zariadení na mieru až po roboty, ostatné úzko spolupracujú s takzvanými integrátormi. V takomto prípade spoločnosť dodáva výhradne roboty a práve integrátori zabezpečujú všetko ostatné.

Prehľad produktov na trhu

FANUC je japonská spoločnosť vyrábajúca robotov založená v roku 1958 a aktuálnym svetovým lídrom robotizácie a automatizácie na celom svete. S viac ako 100 rôznymi modelmi robotov má najväčšie portfólio pokrývajúce takmer všetky priemyselné aplikácie. Okrem robotov je spoločnosť známa výrobou numerických systémov a servopohonov, ale taktiež výrobou vlastných obrábacích centier. FANUC ponúka robotov s užitočným zaťažením do 2,3 tony, jedná sa o robota s najväčším užitočným zaťažení na trhu. Rovnako ponúka množstvo komplexných technologických riešení ako 2D a 3D vizuálna detekcia, kontrola vibrácii, tenzometria pre meranie a kontrolu správnosti súčiastok alebo komunikácia robotov v reálnom čase, čo umožňuje napríklad používanie viacerých robotov na jednej vodiacej koľajnici pre spoločnú obsluhu strojov. Veľmi zaujímavým je aj systém Dual Check Safety, ktorý používaným pozičných senzorov dovoľuje presnú kontrolu polohy robota. Systém využíva takzvanú svetelnú bránu na vymedzenie priestoru v ktorom sa môže pohybovať. V prípade, že do tohto priestoru zasiahne človek alebo objekt, robot je automaticky zastavený. Takéto riešenie je praktické v miestach s obmedzeným priestorom, ale aj kdekoľvek inde pretože umožňuje ušetriť financie za bezpečnostné oplotenie [16],[17].

ABB je švédsko-švajčiarska spoločnosť ktorá vznikla fúziou dvoch spoločností v roku 1988. Jedná sa o svetového výrobcu produktov v oblasti energetiky, elektroniky, robotiky a automatizácie. Spoločnosť je aktívna v 53 krajinách sveta najmä v automobilovom, leteckom a potravinárskom priemysle. Ako jediná z oslovených spoločností nespolupracuje s integrátormi ale všetko zabezpečuje interne. ABB ponúka takmer rovnaké portfólio robotov ako ostatné spoločnosti, teda od kĺbových, cez paralelné až po roboty schopné spolupracovať s človekom. Spoločnosť má množstvo skúseností práve s presným zakladaním súčiastok do strojov, zakladaním do paliet, inou manipuláciou, brúsením alebo zváraním. Rovnako ako FANUC ponúka systém bezpečnostnej svetelnej brány, integrovaný snímač sily, polohovadlá obrobkov alebo na mieru prispôsobené paletizačné chápadlá [18],[19].

KUKA je nemecká spoločnosť s najdlhšou históriou spomedzi oslovených výrobcov, založená už v roku 1898 kedy sa však nevenovala robotike. Prvý robot pod značkou KUKA bol však vyrobený pomerne skoro, už v roku 1973 a jednalo sa o prvý priemyselný robot so šiestimi elektromechanicky ovládanými osami. Ponukou robotov sa spoločnosť odlišuje najmä zameraním a skúsenosťami v oblastiach s ťažkými pracovnými podmienkami ako sú zvýšená teplota alebo manipulácia s nebezpečnými látkami. Tak isto sa zameriava na robotické zváranie a naviac dodáva aj zváracie stroje. Okrem bežného portfólia robotov ponúka systém tzv. omniMOVE, systém pre extrémne presnú manipuláciu s ťažkými súčiastkami [20],[21].

YASKAWA je japonská firma ktorá sa špecializuje na výrobu meničov napätia, servopohonov a robotov. Firma je aktívna na všetkých svetových kontinentoch a pre potreby Európy používa závody v Nemecku, Švédsku a Slovinsku. Typmi robotov sa v ničom výrazne neodlišuje od konkurenčných spoločností, najväčšou výhodou zostáva fakt, že spoločnosť priamo vyrába veľkú časť pohonných mechanizmov robotov čo umožňuje ich priamu optimalizáciu pre potreby firmy [23].

Existujú malé paralelné roboty pre rýchlu manipuláciu s malými súčiastkami, kĺbové roboty s dosahom do 4,5 metra a užitočnou hmotnosťou do 2,3 tony alebo kooperatívne roboty schopné spolupracovať s človekom a nielen vykonávať naprogramovanú funkciu ale tak isto sa inteligentne učiť a zlepšovať. V kombinácii s doplnkovou výbavou ako sú multifunkčné chápadlá prispôsobené na manipuláciu s produktom akéhokoľvek tvaru, inteligentnými vizuálnymi, tlakovými a bezpečnostnými senzormi alebo dráhami umožňujúcimi pohyb robota bez straty presnosti, je možné aplikovať robotizáciu do takmer akéhokoľvek výrobného závodu. Nemusí sa pritom jednať iba o neflexibilnú veľkosériovú výrobu, práve naopak robotizácia nachádza uplatnenie v čoraz viac flexibilnejších výrobných systémoch [16].

NÁVRHY AUTOMATIZOVANEJ VÝROBNEJ BUNKY

Vzhľadom na dostupné informácie o výrobnom procese a na predstavu a potreby firmy PH, boli vypracované viaceré návrhy automatizovanej výrobnej bunky. Tieto návrhy môžu byť rozdelené do dvoch kategórii – implementácia prvkov automatizácie s využitím aktuálne používaných výrobných strojov a implementácia automatizácie spolu s nákupom nových výrobných centier. Keďže automatizácia výrobného procesu je momentálne riešená vo viacerých závodoch PH po celom svete, tieto závody medzi sebou komunikujú a predávajú si užitočné informácie. Dané návrhy budú zamerané najmä na automatizáciu sústružníckych a frézovacích operácii.

Riešenia s využitím pôvodných obrábacích centier

Konfigurácia č.1

Prvý predkladaný návrh je zo všetkých najjednoduchší. Jedná sa o zjednodušenú verziu ktorá opomína niektoré vedľajšie operácie, slúži ako prvotný návrh od ktorého sa budú odvíjať ostatné riešenia. Jeden robot – IRB 4600 - obsluhuje aktuálne používané frézovacie centrá, ktorých upínanie výrobkov však musí byť upravené pre potreby robota. Dopravník vychádzajúci zo sústruhu musí byť tak isto upravený a to tak, aby na ňom bolo integrované zariadenie pre značenie dráh QR kódom. Dopravník musí doviezť osústružené dráhy do dosahu robota a taktiež musí byť slúžiť ako ich odkladací priestor pred frézovacími operáciami.

Operátor dovezie paletu s polotovarmi na určené miesto a manuálne naloží určený počet kusov na dopravník vchádzajúci do sústruhu. Tie po osústružení vychádzajú na druhom dopravníku na ktorom je umiestnené značiace zariadenie až do dosahu robota. Robot je vybavený dvojitým chápadlom schopným manipulovať s rôznymi veľkosťami dráh, stredovými prípravkami a tak isto aj stredovými tyčami. Robot následne založí osústružené kusy do frézovacích centier a zároveň vyloží ofrézované kusy a uloží ich do palety pre tepelné spracovanie. Keďže riešenie nepočíta s úložným priestorom medzi sústružníckymi a frézovacími operáciami, nebude možné vyrábať viac ako jednu veľkosť dráh paralelne.

Jedným z hlavných problémov takejto konfigurácie bude slabé využitie robota, ktorý by pracoval iba ¼ z potenciálne využiteľného času. Ďalším problémom je vznik tzv. zápchy na výrobnej linke ktorá je spôsobená rozdielom vo výrobnom čase súostruhu a frézovacích centier. Dochádza teda k hromadeniu materiálu medzi týmito dvoma operáciami a zapchatiu dopravníku, čo spôsobí zastavenie sústruženia.

Konfigurácia č.2

Základom tohto riešenia je konfigurácia č.1 rozvinutá natoľko aby boli odstránené jej nedostatky. Namiesto jedného robota sú v tejto konfigurácii použité dva, čo vedie k väčšej automatizácii výrobného procesu. Taktiež je počítané so všetkými vedľajšími operáciami potrebnými pre kompletnú výrobu dráh, ktoré boli v predchádzajúcom návrhu zanedbané.

V tomto prípade je jeden robot používaný na manipuláciu s dráhami po sústružení. Zakladá ich do značiaceho zariadenia a v prípade potreby na kontrolnú stanicu. Vďaka používaniu robota vznikne priestor pre častejšiu kontrolu rozmerov, čo vedie k zlepšeniu kvality a zvýšeniu spokojnosti zákazníka. Po vykonaní týchto operácii robot uloží osústruženú a označenú dráhu na odkladaciu paletu. Tá je umiestnené v dosahu oboch robotov takže druhý robot môže dráhy vyberať a zakladať do frézovacích centier. Na rozdiel od predchádzajúceho riešenia je v dosahu druhého robota umiestnená ešte jedna odkladacia paleta, ktorá môže byť predom naplnená už osústruženými dráhami rôznych veľkostí. To umožňuje paralelne obrábať rôzne minimálne dve rôzne veľkosti dráh. Po skončení frézovania robot uloží obrobené dráhy do palety na tepelné spracovanie, ktorá je automaticky naložená do stanice tepelného spracovania pomocou systému dopravníkov.

Robot obsluhujúci frézovacie centrá je umiestnený na pojazde čo mu dodáva väčšiu flexibilitu. Vďaka pojazdu sa robot môže presunúť od frézovacích centier až k miestu vykladania tepelne spracovaných dráh. Odtiaľ ich môže nakladať na dopravník ktorý presunie tepelne spracované dráhy priamo k brúskam. Vďaka tomu je práca operátorov ešte viac zjednodušená. V prípade použitia tejto konfigurácie odpadá operátorom manuálna práca s ťažkými plne naloženými paletami. Modifikáciou sústruhu je možné dosiahnuť ešte rozsiahlejšie zautomatizovanie výrobného procesu a to tak, že robot bude nakladať polotovary na dopravník sústruhu.

Riešenia s využitím nových obrábacích centier

Konfigurácia č. 3

V tomto návrhu je súčasne používané vertikálne sústružnícke centrum nahradené dvomi horizontálnymi sústružníckymi centrami DMG Mori NLX 3000. Nakladanie týchto obrábacích centier už nie je zabezpečované operátorom. Ten síce dovezie paletu s polotovarmi do vymedzeného priestoru, odtiaľ sú však nakladané robotom. Na to je používaniu systém 3D videnia [17]. Robot založí polotovar do prvého sústruhu, kde prebieha prvá polovica sústruženia. Po ukončení tejto operácie robot do stroja založí nový polotovar a ten polo obrobený založí do druhého sústruhu, kde prebieha druhá polovica sústruženia. Následne je proces podobný konfigurácii č.2 a teda každý obrobok je označený, v prípade potreby skontrolovaný a uložený na odkladaciu paletu. Aby bolo predídené vzniku zápchy na výrobnej linke, je kapacita použitej odkladacej palety vypočítaná tak, aby pokryla hromadenie osústružených obrobkov počas celej pracovnej smeny. Na konci tejto smeny je odkladacia paleta vymenená za prázdnu.

Kvôli použitiu dvoch sústruhov, ktoré zaberajú viac pracovného miesta, nie je možné umiestniť robota obsluhujúceho frézovacie centrá na pojazd. Po zvážení technických nedostatkov a diskusii s dodávateľmi robotov sa došlo k záveru, že používanie pojazdov pre roboty je neefektívne. Prvým dôvodom je vysoká zriaďovacia cena a druhým dôvodom je častá údržba ktorá je finančne nákladná a tak isto spôsobuje prerušenie výroby celej bunky.

Konfigurácia je optimalizovaná pre výrobu dvoch veľkostí dráh súčasne. K tomu je prispôsobený aj dopravník prázdnych paliet pre tepelné spracovanie. Existujú dve veľkosti paliet, každá použiteľná pre dve veľkosti dráh čo pokrýva celú škálu výroby. Je však na operátorovi umiestniť palety do správneho poradia tak, aby nedošlo k chybe. Po plnom naložení sú palety automaticky zavezené do stanice termálneho spracovania a tak isto sú aj automaticky vyvezené. Po vychladnutí operátor vyloží dráhy do tzv. KLT prepraviek, paletu rozloží a umiestni na začiatok dopravníka. Nevýhodou tejto konfigurácie je neúplné využitie potenciálu sústruhov, kvôli práci robota. Robot ich nestíha dostatočne rýchlo obsluhovať, preto vznikajú časové prestoje a výroba je spomalená. Naopak druhý robot je málo využívaný, rovnako ako v konfigurácii č.1.

Konfigurácia č. 4

Namiesto dvoch samostatných horizontálnych sústružníckych centier je v tejto konfigurácii použité iba jedno. Jedná sa o stroj NZX 2000 ktorý má dve samostatné vretená a nástrojové revolveri, čo mu umožňuje kompletne osústružiť obrobok bez manipulácie pomocou robota. Zvyšok operácii je podobný predchádzajúcej konfigurácii bez výraznejších zmien. Čas manipulácie obrobku robotom je znížený čo vytvára priestor pre častejšiu kontrolu rozmerov. Vďaka používaniu iba jedného sústružníckeho centra dochádzka k výraznému zredukovaniu potrebného pracovného priestoru. To otvára možnosť inštalácie pojazdu pre robota obsluhujúceho frézovacie centrá, prípadne pre iné využitie vzniknutého voľného priestoru.

Jednou z možností je implementácia druhej kontrolnej stanice. Pôvodná kontrolná stanica je určená na bežnú kontrolu charakteristík. Avšak ako bolo spomenuté v opise aktuálneho výrobného procesu, na prvom a poslednom kuse v sérii musia byť skontrolované viaceré charakteristiky. Tieto charakteristiky nie je možné skontrolovať na jednoduchom prístroji, obrobok preto musí byť vybratý z výrobného cyklu a skontrolovaný operátorom alebo príslušným zamestnancom. Aby toto bolo možné, musí byť upravená aj prvá kontrolná stanica a to tak, aby k nej mal daný zamestnanec prístup a mohol obrobok bezpečne vybrať, preniesť k druhej stanici a tam skontrolovať potrebné charakteristiky.

Konfigurácia č. 5

V tomto návrhu je opäť využívané vertikálne sústružnícke centrum konkrétne FAMAR Tandem 415. Jedná sa o polo-automatické zariadenie ktorého súčasťou je aj dopravníkový pás na transport súčiastok do a zo stroja. Stroj je obsluhovaný robotom, ktorý nakladá neobrobené polotovary na prvú časť dopravníka. Dopravník ich pomocou určených držiakov dopraví až k vretenu, ktoré ich automaticky naberá po jednom kuse a následne presúva k obrábacím nástrojom. Jedná sa o sústruh s dvomi vertikálnymi vretenami, každé z nich určené na obrábanie jednej časti dráhy.

Po skončení sústruženia je každá súčiastka vyložená na druhý dopravníkový pás pomocou druhého vretena. Pás dopraví obrobky do dosahu robota, ten ich odtiaľ presúva k ďalším operáciám. Zvyšok výrobného procesu je rovnaký ako v predchádzajúcej konfigurácii, s rozdielnym umiestnením druhej kontrolnej stanice kvôli väčším rozmerom sústruhu. V porovnaní s prechádzajúcim návrhom je však produktivita sústruhu zvýšená na 150 %, kvôli čomu je potrebné zvýšiť kapacitu odkladacej palety. Druhou možnosťou je zvýšenie kapacity frézovacích centier a to buď optimalizáciou obrábacích operácii alebo investíciou do tretieho frézovacieho centra. K výhodám tohto riešenia patrí menšia vyťaženosť robota, čo môže byť využité k častejšej kontrole rozmerov alebo vykonávaniu iných operácii. Podľa informácii výrobcu sústruhu je nastavovanie obrábacieho procesu pre rôzne veľkostí dráh časovo kratšie ako pri iných strojoch. Nevýhodou tohto riešenia je zlý prístup operátora k ovládaniu sústruhu v prípade poruchy robota.

Konfigurácia č.6

Táto konfigurácia je usporiadaním strojov a priestorom ktorý zaberajú veľmi podobná konfigurácii č.5. Namiesto jedného vertikálneho sústruhu sú však použité dva menšie vertikálne sústruhy Doosan Puma V8300. Výhodou tohto riešenia je úspora miesta a možnosť rýchleho dodania strojov v porovnaní s ostatnými riešeniami. Táto výhoda sa však môže stratiť pretože stroje nedisponujú dopravníkom a musia byť značne modifikované pre možnosť zakladania a vykladania obrobkov robotom. Ďalej, nevýhodou je zvýšený čas manipulácie s obrobkami, pretože každý stroj je podobne ako v konfigurácii č. 3 využívaný na obrábanie iba jednej z dvoch strán dráh. To má za príčinu spomalenie celého výrobného procesu oproti predchádzajúcej konfigurácii. Ďalšou komplikáciou oproti predchádzajúcemu riešeniu je implementácia značiaceho zariadenia. V konfigurácii č. 5 mohlo byť implementované ako súčasť dopravníku ktorý vyváža obrobky zo sústruhu, v tomto prípade musí byť značiaca stanica opäť samostatná a teda čas manipulácie je zvýšený. Robot obsluhujúci sústružnícke centrá je podobne ako v konfigurácii č. 3 preťažený a teda vedľajšie manipulačné operácie spomaľujú hlavné operácie. Na pokrytie nahromadených obrobkov po sústružení bude v tomto prípade stačiť odkladacia paleta s kapacitou 70 kusov.

Konfigurácia č.7

Na rozdiel od prechádzajúcich návrhov, tento kompletne mení usporiadanie strojov a teda aj tok materiálu. Namiesto samostatných obrábacích strojov pre sústruženie a frézovanie sú použité sústružnícko-frézovacie centrá DMG Mori NT4250. Keďže sa jedná o rozmerovo väčšie stroje a je plánové robotom obsluhovať tri takéto centrá, je nutné použiť väčšieho robota. V konfigurácii sú použité celkovo dva roboty, jeden IRB 4600 ako v predchádzajúcich riešeniach a druhý IRB 6640, ktorý bude obsluhovať spomínané sústružnícko-frézovacie centrá.

Tri obrábacie centrá sú umiestnené blízko seba a obsluhované väčším robotom. Robot nakladá polotovary z paliet ktoré sú dovezené operátorom, pričom je rovnako ako v predchádzajúcich riešeniach využitá 3D vízia. Takáto konfigurácia umožňuje obrábanie troch rôznych veľkostí dráh paralelne. Po dokončení obrábacích operácii sú obrobky naložené na dopravník ktorý ich dovedie do druhej časti bunky. Na dopravníku je implementované značiace zariadenie schopné označiť všetky druhy a veľkosti dráh. Po značení sú dráhy rozdelené na základe veľkostí do jedného z troch zberačov. Odtiaľ sú dráhy ukladané druhým robotom do paliet na tepelné spracovanie. V prípade potreby sú dráhy skontrolované na kontrolnej stanici umiestnenej v dosahu robota. Zvyšok operácii výrobnej bunky nie je automatizovaný.

Takéto riešenie síce ponúka možnosť obrábania troch rôznych veľkostí dráh paralelne, avšak takéto nastavenie výrobného procesu nie je optimálne. Časy obrábacích cyklov sa menia v závislosti na veľkosti dráhy, čo v prípade obrábania 3 rôznych veľkostí paralelne ústi do dezorganizácie postupnosti týchto operácii.

Vďaka kompletnej zmene strojového parku sa môže jednať o organizačne najjednoduchšie riešenie, aj keď si vyžaduje úplne zastavenie výrobného procesu na minimálne dva týždne. Výhodou je zredukovanie manipulačného času a aj zníženie počtu upínaní, vďaka čomu sa znižujú chyby spôsobené práve upínaním. Nevýhodou takéhoto riešenia je zníženie produktivity oproti predchádzajúcim riešeniam. Napríklad v porovnaní s konfiguráciou č. 5 je produktivita celej bunky v tomto prípade iba 30%. Tento návrh ale nemusí byť zavrhnutý, ako je to spomínané v diskusii.

INVESTIČNÁ ANALÝZA

Pri investovaní do projektov s dlhšou dobou návratnosti je ekonomický faktor jedným za najdôležitejších, najmä pri predkladaní návrhov vedeniu firmy. Pri investovaní do automatizácie výroby sa miera investícii priamo úmerne zvyšuje s požadovanou diverzitou vyrábaných produktov [40]. Existuje množstvo rôznych výrobcov robotov a spoločností zaoberajúcich sa automatizáciou výroby. Každá z nich má svoju vlastnú predajnú stratégiu a teda aj vlastné ceny za produkty a služby. Keďže sú technické parametre ponúkaných produktov často podobné, všetky uvedené sumy sú vypočítané ako priemerné po porovnaní viacerých ponúk.

Táto analýza je orientačná pre predstavu o akú úroveň investícii sa jedná. Sú v nej započítané najvýznamnejšie položky okrem ktorých existuje ešte množstvo ďalších, ktoré však nemajú výrazný vplyv na výslednú sumu investície. Ceny sú uvedené bez daňovej položky a v prípade strojov a robotov zahŕňajú všetky náklady vrátane dopravy, inštalácie a oživenia.

Tab. 1 Výška investícii do jednotlivých

	#1	#2	#3	#4	#5	#6	#7
Č.1 [€]	411000	701000	975000	1190000	1460000	1090000	2685000
Č.2 [€]	1061000	1481000	1575000	1890000	2063000	1870000	-

Tab. 2 Dĺžka návratnosti investícii jednotlivých

	#1	#2	#3	#4	#5	#6	#7
Návratnosť č. 1 [rok]	11,8	10	14	17	21	15,6	38,5
Návratnosť č. 2 [rok]	30,5	22,3	22,6	27,1	29,6	26,8	-

Tab. 1 zobrazuje vypočítanú výšku investícii pre každú navrhovanú konfiguráciu, pričom investícia č.1 sa vzťahuje na navrhnutú konfiguráciu s použitím pôvodných frézovacích centier v investícii č.2 sa počíta s nákupom nových frézovacích centier, v ostatných smeroch sú konfigurácie rovnaké. Tab. 2 zobrazuje dĺžku návratnosti investícii pre obe možnosti. Časy návratnosti sú dlhé, avšak boli vypočítané iba na základe ušetrenia na mzdách a nákladoch na operátorov. Reálne časy návratu investícii môžu byť výrazne kratšie, pokiaľ sa k ušetreniu na operátoroch pridajú ostatné faktory popísané v diskusii.

DISKUSIA

Modernizácia a zlepšovanie výrobného procesu sú veľmi dôležitým faktorom na udržanie konkurencie schopnosti pre každú výrobnú spoločnosť. Optimalizácia výrobného procesu, eliminácia sekundárnych operácii a finančné úspory sú kľúčom k úspechu. Obrábací proces dráh v PH Brno je dobre optimalizovaný a prispôsobený súčasnému strojovému vybaveniu. Po jeho zanalyzovaní boli však zistené možné zlepšenia najmä v sekundárnych operáciách.

Príkladom takýchto zlepšení je čistenie obrobkov od triesok a chladiacej kvapaliny, ktoré by mohlo byť zautomatizované pomocou inštalácie systému ofukovania stlačeným vzduchom na konci obrábania. Ďalšou možnosťou odľahčenia operátora a urýchlenia výroby je použitie špeciálneho odihlovacieho nástroja. Ten by bol uložený v zásobníku a na konci obrábacieho cyklu by obrobky po naprogramovaní odihlil. Ďalej je možné integrovať značiace zariadenie priamo na výstupný pás sústruhu. Zároveň je možné nahradiť pôvodné značiace zariadenie, ktoré využíva mikroúder, novým zariadením ktoré funguje na princípe laserového značenia. Tento spôsob značenia je preferovaný zo strany zákazníka a naviac je časovo menej náročný ako pôvodné riešenie.

Napriek tomu, že sa táto práca nezaoberá druhou výrobnou bunkou dráh kde prebieha brúsenie krivky a honovanie, boli tieto výrobné procesy zanalyzované. Používané brúsky majú otočný stôl podobne ako frézovacie centrá a to znamená, že súčiastka upevnená na prvej polovici stola je obrábaná zatiaľ čo k druhej strane stola má operátor prístup a môže upevniť ďalšiu súčiastku. Takéto paralelné vykonávanie operácii vedie k urýchleniu celého výrobného procesu. Celý proces môže byť ešte viac zrýchlený použitím nového upínača na ktorý by bolo možné upevniť dve dráhy súčasne. Aktuálne používaný brúsny nástroj je dostatočne dlhý na to, aby s ním bolo možné obrábať dve dráhy upevnené za sebou. Limitujúcimi faktormi v tomto prípade by boli výkon stroja a problém s ohýbaním nástroja.

Hlavným dôvodom zvažovania automatizácie výrobnej bunky je rastúci nedostatok pracovnej sily. Aj keď to nemusí byť prípad pobočky PH v Brne, projektom automatizácie sa aktuálne zaberajú viaceré pobočky PH po celom svete. Je preto praktické sa týmto projektom zaoberať súčasne aj v Brnenskej pobočke a vymieňať si získané poznatky v rámci celej firmy.

Okrem výslednej ceny investície a dĺžky návratnosti, sú významnými faktormi taktiež flexibilita konfigurácii a úroveň modernizácie ktorú pre spoločnosť prinesú. Flexibilita v tomto prípade predstavuje možnosť prispôsobiť obrábacie procesy na výrobu iných typov výrobkov, ale aj rýchle nastavenie obrábacieho procesu pre rôzne veľkosti dráh. To môže byť dôležité napríklad pri nepredpokladanom zvýšenom dopyte po konkrétnej veľkosti motora, čo vedie k potrebe zvýšenej produkcie istej veľkosti dráh. Napríklad konfigurácia #7, ktorá ma zo všetkých navrhovaných konfigurácii najvyššiu investičnú cenu, môže byť vďaka vysokej flexibilite jedným z najlepších z navrhovaných riešení. Podobne aj úroveň modernizácie môže ovplyvniť voľbu konfigurácie, pretože obrábacie stroje aj ostatné zariadenia sú postupne opotrebovávané čo vedie k zvýšeniu servisných investícii. To nepriamo vedie k zvýšenému času nečinnosti strojov. K tomuto faktoru sú ďalej viazané dva významné problémy – komunikácia robotov so strojmi a splnenie bezpečnostných predpisov. Obzvlášť druhý problém môže byť veľmi neočakávaný, keďže stroje doteraz spĺňali všetky bezpečnostné predpisy a normy. Tieto normy sa však z roka na rok menia a v prípade vytvorenia automatizovanej výrobnej bunky, musí bunka ako celok spĺňať všetky aktuálne predpisy a normy. To môže byť problém pre staršie obrábacie stroje a zariadenia, pretože tie boli navrhnuté tak aby potrebné predpisy spĺňali v dobe ich výroby. V plnej verzii práce sú opísané mnohé ďalšie problémy a komplikácie na ktoré bolo pri tomto projekte narazené.

Celá práca je postavená na analytickom riešení problému a spolu s požiadavkami spoločnosti to boli základné piliere pre vypracovanie návrhov. V projekte je potrebné pokračovať a na problematiku sa pozrieť z iných hľadísk ako napríklad z hľadiska logistiky, organizácie pracovísk alebo detailnej ekonomickej analýzy. To by poskytlo komplexnejší pohľad na situáciu a uľahčilo by to výber správneho riešenia.

ZÁVER

Táto práca bola vypracovaná priamo v priemyselnom prostredí a obsahovo rieši reálne existujúce možnosti. Počas doby riešenia bola viac krát pozmenená a prispôsobená skutočným problémom a rozhodnutiam, na základe ktorých boli vypracované viaceré návrhy finálneho riešenia. Každé zo siedmych navrhnutých riešení obsahuje mapu vykonávaných operácii a ich podrobný opis, pričom zdôrazňuje ich hlavné výhody a nedostatky. Každý návrh tak isto obsahuje obrázky z jeho 3D modelu a časť tzv. Ganttovho grafu ktorá je okomentovaná.

Navrhnuté konfigurácie sú rôznorodé a navzájom sa od seba odlišujú, aby poukázali na variabilitu finálneho návrhu. Vďaka integrácii rôznych prvkov automatizácie a obrábacích centier boli odhalené viaceré skryté problémy. Tieto problémy môžu byť prediskutované interne v spoločnosti PH alebo s externými firmami, za účelom dosiahnutia optimálneho riešenia. Súčasťou prácou je taktiež jednoduchá investičná analýza pre každú navrhnutú konfiguráciu, ktorá ukazuje orientačnú výšku potrebných investícii.

Automatizácia výroby v už fungujúcej výrobnej spoločnosti je komplexný problém, ktorý vyžaduje dôkladné plánovanie. Vypočítaná dĺžka návratnosti vypadá ako prekážka, ktorá zastaví realizáciu tohto projektu. Hlavným problémom, je potreba relatívne vysokej flexibility automatizovanej výrobnej bunky. Aby mohol byť tento projekt zrealizovaný, je potrebné sa zamerať na zvýšenie produktivity automatizovanej bunky. Väčšia produktivity znamená väčší zárobok a väčší zárobok znamená kratšiu návratnosť investícii. Na základe toho, sa odporúča sústrediť sa na hlbší rozvoj návrhov #4, #5 a #6 ktoré majú najväčšiu produktivitu. Pri odhadovanej predajnej cene 50€ za vyrobenú dráhu a zvýšení produkcie iba o 5% za deň, sa doba návratnosti konfiguráciu #5 zníži na približne 5 rokov, namiesto pôvodných 21. Keď sa k tomu pripočíta cena za ušetrenú plochu v továrni spolu s faktorom modernizácie strojového parku, projekt sa stáva realizovateľným.

Práca zhromažďuje a zhŕňa informácie o automatizácii flexibilnej výroby a môže byť užitočná pre rôzne spoločnosti, ktoré začínajú nový projekt automatizácie. Potvrdzuje, že ideálna konfigurácia musí byť vysoko produktívna a mala by zaberať čo najmenej priestoru. Tak isto ukazuje, že spoločnosti by sa nemali báť vyšších investícii. V ideálnom prípade by sa mali pokúsiť zrealizovať kompletne nové automatizované pracovisko a pôvodné stroje využiť na iné účely.

Spolu s bližšími informáciami ku každej konfigurácii, práca slúži spoločnosti ako základný zdroj informácii pre automatizáciu pracovísk. Tieto informácie môžu byť komunikované s ostatnými závodmi PH po celom svete a uľahčiť tak začiatok projektov týkajúcich sa automatizácie.

ABSTRACT

Introduction

Ce travail a été en collaboration avec l´entreprise Poclain Hydraulics (ci-après PH), spécialiste mondial de la transmission hydrostatique. Cette entreprise de l´origine française se spécialise dans la production des pompes, des moteurs hydrauliques et des valves. Toutes les informations ont été analysés dans l´usine de Brno en République Tchèque. Cet affiliation se spécialise dans la fabrication des parties internes des moteurs hydrauliques, tel que des rotors ou des cames.

Le travail se concentre sur les possibilités d´automation et de robotisation de la cellule de production des cames pour des moteurs de type « MS ». Une came est une partie statique du moteur, qui est constamment soumis aux efforts mécaniques et thermiques. Il s´agit donc d´une partie critique qui influence directement la durée de vie des moteurs, aussi que leur efficacité. L´usine a Brno est la seule usine de l´entreprise en Europe qui fabrique les cames de ce type. Elle sert aussi comme le fabricant de ces cames pour le marché en Asie, plus concrètement en Inde. Il est alors nécessaire de minimaliser le nombre de déchets et assure une haute productivité.

L´idée principale de ce travail est de faire une introduction théorétique, d´analyser la production actuelle de la cellule des cames pour des moteurs de type « MS », de faire résumer des possibilités d´automation at de robotisation et de proposer des configuration d´une cellule de fabrication automatisée. Au début sont définies les spécifications de l´entreprise qu´il faut respecter. Chaque configuration proposée contient une analyse du flux de travail, une description de chaque opération, une visualisation et une comparaison avec la situation actuelle.

ANALYSE THÉORÉTIQUE

Moteurs hydrauliques

Un moteur hydraulique est un actuateur mécanique qui transforme l´énergie potentielle hydraulique en énergie mécanique tournante. Les moteurs hydrauliques peuvent être diviser en moteurs à grande et à petite vitesse. Dépendant du type de construction sont les moteurs encore divisés en moteurs aux dents, aux pelles et aux pistons. Tous les types fonctions sur le même principe – la différence de pression sur deux côté d´actuateur qui avec synchronisation précise assure la rotation de l´arbre de sortie [1].

PH est spécialisé dans la fabrication des moteurs aux pistons et plus concrètement des moteurs aux pistons radiales. Le principe de fonctionnement de ce type de moteur est basé sur le mouvement des pistons. Ce mouvement est assuré par le changement de la pression du liquide amené dans les pistons. Le piston est fixé sur le cylindre qui est lié avec l´arbre de sortie. Quand le piston sort de l´enveloppe, il touche la came, La géométrie de la came est dessinée pour que les force crées assurent la rotation du cylindre. L´avantage de ce type de moteur est la possibilité de changer la direction de la rotation de la façon continu. Les moteurs fabriqués par PH sont concentriques, ce qu´assure les forces radiales équilibrés. Grace à ça, le démarrage des moteurs este rapide est et continue et il est possible de les utiliser sur des basses vitesses de rotation.

L´avantage des moteurs en comparaison avec la concurrence est une haute efficacité et aucunes pertes causées par des transmissions. C´est des moteurs fonctionnant à basses vitesses avec un petit moment cinétique et un couple de rotation constant. Ce type de moteurs est souvent usé dans des différents secteurs d´industrie qui utilisent la machinerie lourde [3].

Automation

Automation est une partie indispensable de la production moderne qui offert la possibilité d´augmentation de la capacité de production sans la diminution de sa qualité. C´est une partie de l´évolution technique qui consiste de la fabrication sans l´intervention directe de l´homme, Automation a commencé à se développer au début du vingtième siècle avec l´arrivé des ordinateurs modernes. La définition d´automation est l´utilisation des éléments technologiques automatiques, qui sont contrôlés strictement par un programme définit en avance. Dans les formes d´automation supérieurs s´utilisent des capteurs qui contrôlent activement la situation actuelle. Grace à ces informations, le processus est doucement adapté en temps réel afin de respecter les conditions définies, sans l´intervention d´opérateur [6].

L´intervention d´opérateur dans le processus de fabrication est le plus souvent nécessaire en cas d´urgence ou de situations improbables. Elle est aussi nécessaire pour les opérations secondaires qui sont trop compliqué ou économiquement exigeants. Comme exemple on peut prendre la prise d´une pièce posé librement ou sans la position définie. Pour des situations semblables, un convoyeur ou autre système de transport est utilisé. La pièce est transportée dans une zone définit et en utilisant la vision 2D ou 3D, le robot est capable de la récupérer [6].

Système de production

Un système de production est une unité de production quelconque, qui peut être considéré comme isolée d´un point de vue, par exemple un atelier ou une usine. Comme l´unité de base d´un système de production est en générale considéré un lieu de travail. Une machine avec un magasin d´outil ou un échanger de palettes est considéré comme un lieu de travail. Si des lieux de travail et le transport du matériau parmi eux est automatisé, il est considéré comme un système de production automatique. Ces systèmes sont divisés en deux grandes catégories – rigides ou flexibles. Des systèmes automatiques rigides sont caractérisé par une cadence de production très élevé mais par l´impossibilité de produire des produits divers. Par contre des systèmes automatiques flexibles ont une cadence moins élevée, mais offrent la possibilité de fabriquer plusieurs types de produits [5].

Système de production flexible

Une unité de production flexible est composée d´une machine qui est capable d´un fonctionnement au moins semi-automatique. Une cellule de production flexible est composée de plusieurs machines qui sont contrôlées par un ordinateur. Un système de production flexible est composé de plusieurs cellule qui sont liées par un système de transport. Il s´agit d´un ensemble de lieux de travail contrôlé par un ordinateur capable d´une production des pièces définie en avance, avec le besoin d´intervention humaine minimale. Un système de ce type permet de produire des produits variés, mais il est financièrement beaucoup plus couteux qu´un système de production rigide. Les systèmes de production sont habituellement améliorés aux systèmes de production automatisées par étapes. Il est donc nécessaire que chaque étape d´amélioration permet le fonctionnement du système d´origine [5].

Robotisation

Les robots ont été rapidement développés de la théorie en pratique autours de l´année 1970, en raison d´augmentation de la quantité et de la qualité de production. L´augmentation de la production est leur avantage la plus importante, parce que les robots peuvent travailler 24 heures par jour sans pause. En plus, leur opération est beaucoup moins chère que celle d´une ligne de production non-automatisée. Les robots ne deviennent pas fatigués, ne se pas distraits ni émotionnels ce que diminue le risque des accidents sur le lieu de travail. Grace à ça, il est utile de les utiliser pour le travail dans des conditions difficiles et dangereux comme par exemple la haute température ou le milieu toxique. Sauf l´augmentation de la production, la précision du travail est plus élevée que celle des opérateurs et ils remplacent des travaux physiquement difficiles [8].

Pendant l´évaluation de l´application des robots est nécessaire de considérer des facteurs comme le temps de cycle, la forme et la tolérance géométrique de la pièce fabriquée, la charge utile, la mémoire, le facteur humaine et le prix. Le robot industriel est d´après la norme ISO 8373 :1994 définie comme un manipulateur polyvalent pour un fonctionnement dans trois ou plusieurs axes, qui est contrôlé automatiquement. Un manipulateur est une machine avec une unité de mouvement double et un guidage pour une manipulation automatique avec des pièces. Les robots peuvent être équipés avec des outils d´usinage divers, des bras ou d´autres outils de manipulation [8].

D´un point de vue mécanique, les robots sont composés des pales et de joints. Actuellement, la plupart des robots ont six degrés de mouvement sauf les petits robots ou des robots à usage unique. L´effecteur du robot est une partie importante qui sert à l´attachement des outils. Elle influence directement la position et l´orientation de la pièce [9].

Le système de commande traite les informations de l´ordinateur de commande et des senseurs et le robot est navigué à la base de ces informations. La navigation d´un robot est un système complexe des microprocesseurs. Un panneau de commande est aussi une partie de robot, par laquelle l´opérateur peut le corriger ou le commander [9].

L´ANALYSE DE LA SITUATION ACTUELLE

Le processus de fabrication actuel

Le processus de fabrication actuel commence par l´achat des semi-produits chez un fournisseur qui sont ensuite usinés sur les dimensions demandées. Les opération d´usinages effectués sont le tournage, le fraisage, le traitement thermique, la rectification et le rodage. Il y a deux cellules de fabrication indépendantes pour couvrir ces opérations dont seulement une va être automatisée. La rectification de la courbe des cames et le rodage ne vont pas être analysés, comme elle se situent dans la deuxième cellule de fabrication. La complexité d´automation est accentuer par le fait que plusieurs tailles des cames sont fabriquées en parallèle sur les mêmes machines. A cause de ça, les machines doivent être assez flexible et l´opérateur doit être capable de les régler rapidement. La production est actuellement optimisée pour 4 différentes tailles de cames.

Tournage

La première opération est le tournage qui est composée de deux cycle. La came est transportée sur un convoyeur qui est chargé par l´opérateur. Il s´agit d´une machine de tournage verticale avec deux broches, chaque est utilisé pour une des deux cycles. Les pièces ensuite sortent sur un deuxième convoyeur, d´où ils sont récupérés par l´opérateur. Les pièces sont nettoyées avec de l´air comprimé et placés dans le marquer. Chaque came est marquée avec un QR code qui porte des informations sur son type. Chaque dixième pièce est contrôlée par l´opérateur afin d´assure la précision d´usinage. A part de cette contrôle régulier, les dimensions sont vérifiées après le changement de l´outil d´usinage. La première et la dernière pièce du lot passe par un contrôle plus détaillé. Après tout ça, la pièce est placée dans une boite qui sert comme un lieu de déposition avant l´opération suivante.

Fraisage

L´opération suivante est le fraisage de la pièce sur une des deux fraiseuses horizontales. Les deux machines sont identiques et ce sont des fraiseuses « duoblock ». C´est un type d´architecture de machine avec une table rotative divisé en deux parties dont un est toujours à l´intérieur de la machine pour l´usinage et la deuxième est accessible pour l´opérateur. En plus, dans chaque partie est placé une deuxième table rotative ce qui offre l´installation de huit montages de serrage différents. Ceci permet une rapide montage de cames des tailles différents. Les cames sont montés avec la précision de montage de 0,01 mm par 2-4 dépendant sur leur taille. Les deux machines sont opérées par un opérateur et fonction en parallèle. Apres l´usinage, les cames sont nettoyées par l´air comprimé, les arêtes sont meulées manuellement par l´opérateur et les pièces sont ensuite placer sur une palette pour le traitement thermique. Pareil comme après le tournage, les dimensions des pièces sont régulièrement contrôlées par l´opérateur et la première et la dernière pièce du lot est contrôlés plus profondément.

Le reste d´opérations

Les cames fraisées sont positionnées dans une palette spéciale pour le traitement thermique. C´est une palette métallique composée de plusieurs parties. Des barres de centrage sont fixées sur une grille, ensuite les cames sont enfilées sur ces barres et des cercles de centrage sont placer entre les came pour éviter leur contact physique. Quand la palette est remplie complètement, l´opérateur l´amené sur système de levage et à partir de ce moment le processus est automatisé. Cette opération est le plus longue de toute les opérations de la fabrication des cames, elle peut durer de 5 à 9 heures et la capacité de la station thermique est deux palettes en même temps. A la fin du procès, les palettes sont automatiquement amenées sur le même système de levage qu´au début. Après le refroidissement sur la température ambiante, les cames sont déchargées dans des boites de déposition par l´opérateur.

La dernière opération dans cette cellule de production est la rectification de surface sur deux rectifieuses horizontales. Les cames sont montées par 5 à 8 pièces sur une table magnétique. A cause de ça, elles doivent être démagnétisées après la rectification et ensuite déposées dans des boites de stockage comme après le fraisage. De nouveau, il y a un contrôle de dimension régulière sur chaque cinquième pièce cette fois. La première et la dernière pièce du lot sont contrôlées plus profondément.

Pendant la planification de la configuration d´une cellule de production, il est nécessaire de prendre en compte toute les facteurs qui l´influences ou avec lesquels elle peut interagir. Ça peut être l´environnement, le réseau, la maintenance ou l´opérateur. Tous ces facteurs créent des limitations qui peuvent être plus ou moins flexibles. Il faut alors créer un résumé de ces facteurs et des possibilités de modification afin de trouver une solution optimale.

L´IDENTIFICATION D´ÉLEMENTS D´AUTOMATION EXISTANTS

L´automation de la production est actuellement un grand projet de tout le group PH dans plusieurs filiales dans le monde. Afin de garder l´objectivité, il est normal de contacter plusieurs entreprises spécialisées dans l´automation et dans la robotisation. Dans ce cas, quatre fabricants de robots ont été contacter dont FANUC, ABB, KUKA et YASKAWA. Un rendez-vous dans l´usine de PH a été arrangé avec l´agent d´affaires de chacune de ces entreprises. Pendant la rencontre, les agents ont pu visité l´atelier de production et voir la ligne de production actuelle, ainsi que les demandes de l´entreprises leur ont été communiqués. Chaque fabricant a une stratégie de marché différente et ils peuvent livrer tout l´équipement nécessaire pour l´automation ou ils livrer seulement l´équipement robotique et ensuite collaborer avec d´autres entreprises – des intégrateurs - qui s´occupent du reste.

Revue des produits sur le marché

FANUC est un fabricant de robots japonais fondée en 1958 et actuellement le leadeur mondial de la robotisation eu automation. Avec plus de 100 modelés de robots différents, il a le plus grand portfolio couvrant presque toutes les applications industrielles. Sauf la production des robots, l´entreprise est connue pour sa production de système de contrôle, des servo-entraînements et aussi des centres d´usinage. FANUC offre des robots avec la charge utile jusqu´au 2,3 tonnes, il s´agit du robot avec la plus grande charge utile sur le marché. En même temps, elle offre une quantité de solutions technologiques comme par exemple la vision 2D et 3D pour les robots, le contrôle des vibration, l´extensiométrie ou la communication des robots en même temps. Le système « Dual Check Safety » est très intéressant, grâce a des senseurs de position il permet de contrôler la position exacte du robot. Ce système fonction comme une porte de lumière pour définir la zone dans lesquelles le robot peut accéder. Si les senseurs détectent un objet extérieur dans cette zone, le robot est automatiquement arrêté. Cette solution est pratique en cas de l´espace limité est permet aussi d´économiser l´investissement dans la clôture de sécurité [16], [17].

ABB est une entreprise suède-suisse qui a été créé par une fusion de deux entreprises en 1988. C´est un fabricant de produits mondial dans la domaine d´énergétique, d´électrotechnique, de la robotisation et d´automation. L´entreprise est active dans 53 pays du monde, le plus souvent dans l´industrie d´automobile, d´aéronautique et alimentaire. C´est la seule des quatre entreprises contactées qui ne collabore pas avec des intégrateurs. ABB offre un portfolio de robots similaire a FANUC et la base des solutions technologiques est aussi pareil, mais ABB offre ces propres systèmes et solutions [18],[19].

KUKA est une entreprise allemande avec la plus longue histoire parmi les quatre entreprises, elle a été fondée en 1898 mais en cette année elle ne travaillait pas dans la robotique. Le premier robot de l´entreprise a été fabriqué en 1973 et c´était le premier robot industriel avec 6 axes contrôlées électro-mécaniquement. Le portfolio des robots et un peu différents que chez les autres entreprise, spécialisé plus dans l´industrie lourde et le travail dans des conditions difficiles comme une haute température ou la manipulation avec des substances toxiques. En plus elle a de nombreuse expérience avec le soudage robotisé et offre aussi des machines de soudage. Sauf les robots, elle est connue pour ces manipulateur « omniMOVE » qui sont utilisées pour la manipulation avec des objets lourds et de grande taille [20],[21].

YASKAWA est une entreprise japonaise spécialisée dans la fabrication des convertisseurs de courant, des servo-entraînements et des robots. Elle est présente sur toute les continents et pour les besoins d’Europe elle utilise les usines en Allemand, Suède et en Slovénie. Elle n´offre pas des types do robots ou de la technologie différente de sa concurrence. Ron plus grand avantage est le faite qu´elle produit la grande partie des mécanismes de mouvement des robots, permettant d´optimiser leur forme en les prenant en compte [23].

Le marché de robots est assez vaste, on y trouve des petits robots parallèles pour une manipulation rapide avec des petites pièces, des robots avec le rayon de 4,5 m et la charge outille de 2,3 tonnes. Il existe déjà des robots collaboratifs, capable de travailler avec les humains sans le danger d´accident et aussi des robots intelligents capable d´apprendre et de s´améliorer. Ensemble avec l´équipement technologique tel que les bras polyvalents, des senseurs visuels, de pression ou de sécurité, il est possible d´implémenter les robots pour presque toutes les applications industrielles. De plus en plus, ça peut être la production flexible [16].

PROPOSITIONS DES CELLULES DE PRODUCTION AUTOMATISÉES

Plusieurs proposition d´une cellule de production automatisée ont été créés, basé sur les informations du processus de production actuel et sur les demandes de l´entreprise. Ces propositions sont divisées en deux catégorie – l´implémentation des éléments d´automation en utilisant les machine d´usinages actuellement utilisés et en utilisant les machines d´usinages nouveaux. Les propositions décrivent surtout l´automation des opérations de tournage et de fraisage.

Solutions utilisant les machines d´usinages actuellement utilisés

Configuration #1

La première proposition est la plus simple parmi toutes. C´est une version simplifiée qui néglige certaines opérations secondaires, elle sert comme la proposition primordiale à partir de laquelle vont être développés les autres propositions. Un robot – IRB 4600 – opère les machines de fraisage. Le montage des pièces doit être adapté aux besoins du robot. Le convoyeur sortant du tour doit être modifié. Une machine marquage doit être intégrée sur le convoyeur et il doit amener les cames marquées dans le rayon du robot et en même temps servir comme un lieu de stockage des cames avant le fraisage.

L´opérateur amené une palette avec des demi-produit est charge manuellement le convoyeur du tour. Les pièces sont pose sur le deuxième convoyeur après les opérations de fraisages. Le robot équipé d´un double bras est capable de manipuler avec des tailles différentes de cames, des barres de centrage aussi qu´avec des cercles de centrage. Le robot charge les centres de fraisage avec des nouveau pièces tournées et décharge les pièces fraisées dans la palette pour le traitement thermique. Comme la solution ne compte pas avec d´autre espace de stockage que le convoyeur, il est impossible d´usiner plus qu´une taille de came en même temps.

Un des problèmes de cette configuration est un usage de robot bas, seulement ¼ du temps potentiellement usé. Le deuxième problème est la création de l´embouteillage sur la ligne de production, causé par la différence de temps de cycle entre les différents machines d´usinage. Les cames tournées sont accumulées sur le convoyeur ce que cause l´arrête de tournage après un certain temps.

Configuration #2

Cette configuration est basée sur la configuration #1 et elle est développé afin d´éliminer les besoins de la première. Deux robots sont utilisés au lieu d´un, ce que mène vers une plus grande automation. Toutes les opérations qui ont été négligées sont maintenant inclues.

Le premier robot est utilisé pour la manipulation avec les cames après le tournage. Il les charge dans la machine de marquage et dans la station de contrôle des dimensions, si c´est nécessaire. Grace à l´utilisation du robot se crée de l´espace pour une contrôle de dimension plus souvent, ce qu'améliore la qualité et la satisfaction du client. Après ces opérations, le robot pose la came tournée et marquée sur une palette de stockage. Cette palette est dans le rayon des deux robots pour que le deuxième puisse les charger dans les machines de fraisage. Sauf une palette de stockage, il y a une deuxième palette dans le rayon du deuxième robot. Cette palette peut être charge avec d´autres tailles de cames ce que permet l´usinage de plusieurs tailles en parallèle. Apres l´opération de fraisage, les cames sont placées dans la palette pour le traitement thermique. Quand la palette est remplie, elle est automatiquement transportée dans la station a traitement thermique sur un convoyeur.

Le robot opérant les deux machines de fraisage est posé sur un rail augmentant sa flexibilité. Il peut se déplacer jusqu´au lieu de décharge des cames après le traitement thermique et ensuite les charger sur un autre convoyeur qui les amène jusqu´aux rectifieuses. Tout ça simplifie encore plus le travail des opérateurs et élimine le travail manuel avec des pièces lourdes.

Solutions utilisant des nouveaux machines d´usinage

Configuration #3

Dans cette proposition, le tour vertical qui est actuellement utilisé est remplacé par deux tours horizontales DMG Mori NLX 3000. Le chargement de ces centres est automatisé et assuré par un robot. L´opérateur amène une palette avec des demi-produits et le robot grâce à l´utilisation d´un système de 3D vision est capable de les charger de cette palette. Le robot charge le premier tour ou la première partie de tournage est faite. Après il remplace la première pièce par une deuxième et charge la premier dans la deuxième machine de tournage. Le reste d´opérations est similaire à la configuration précédente – les cames sont marquées, contrôlées et ensuite fraisées. Pour éviter la création d´embouteillage, la capacité de la palette de stockage est calculée pour couvrir l´accumulation des pièces pendant 8 heures de travail. Quand les opérateurs se changent, ils changent la palette remplie par une nouvelle qui est vide.

Comme les deux centres de tournage utilisées occupent ensemble plus de place, il est impossible de placer le deuxième robot sur un rail. Apres l´analyse d´inconvénients techniques du rail, il a été constaté que ce n´est pas une solution utile pour les besoins du PH.

La configuration est optimalisée pour la production de deux tailles de cames différentes en parallèle. Le convoyeur des palettes vide pour le traitement thermique est créé pour cette configuration. La production compte avec la fabrication de 4 tailles de cames différentes au total et pour couvrir cette production, deux types de palette pour le traitement thermique sont suffisants. Les palettes remplies sont transportées dans la station de traitement thermique automatiquement et après cette opération, un operateur les décharge comme dans la configuration #1. Le plus grand inconvénient de cette configuration est l´utilisation incomplète du potentiel des tours. Ceci est causé par une surcharge du robot qui les opère, car il s´occupe de beaucoup d´opération et les temps de manipulation excèdent le temps du cycle d´usinage. Au contraire, le deuxième robot n´est pas assez utilisé comme dans la configuration #1.

Configuration #4

Au lieu de deux tours séparés, seulement un est utilisé dans cette configuration. C´est un NZX 2000 de DMG Mori qui a deux broches et deux revolvers à outils indépendantes ce que permet de tourner la pièce complétement. Le temps de manipulation est alors raccourci et grâce à ça, il est possible d´augmenter la fréquence du contrôle de dimension. Un autre avantage de cette proposition est qu´il y a plus de place libre comme seulement une machine de tournage est utilisée. Le reste d´opérations est similaire à la configuration #3.

Une des possibilité d´utilisation de l´espace libre est installer une deuxième station de contrôle. La première sert au contrôle de dimension régulier, alors que la deuxième peut servir au contrôle de dimension au début et à la fin du lot. Ce contrôle est plus complexe à faire et peut demander l´intervention d´opérateur. La première station de contrôle est donc modifiée pour que l´opérateur puisse accéder les pièces sans l´entrée dans la zone de robots. Il sort la pièce de la première station, contrôle les dimensions sur la deuxième et ensuite retourne la pièce dans la première station d´où elle continue dans le processus d´usinage.

Configuration #5

Cette configuration utilise un nouveau centre de tournage vertical – FAMAR Tandem 415. C´est une machine semi-automatique avec un convoyeur pour le transport des pièces dans la machine et ensuite pour les sortir. La machine est opérée par un robot qui tout d´abord charge le convoyeur avec des demi-produits d´une palette amené par l´opérateur. Les pièces sont fixées sur un support par un. C´est une machine a deux broches dont chacune fait une partie de tournage.

A la fin d´usinage, les pièces sont déposées sur un support du deuxième convoyeur qui les amenés dans le rayon du robot. Le reste d´opérations est similaire à la configuration précédente, même si la configuration des machines dans l´espace est un peu changée. Mais, la productivité de cette configuration est augmentée a 150% par rapport à la configuration #4, il est alors nécessaire d´augmenter la capacité de la palette de stockage avant le fraisage. Une deuxième option est d´investir dans une troisième machine de fraisage pour couvrir la production du tour. D´autres avantages de cette configuration sont une bonne utilisation du premier robot et des ajustements rapides pour l´usinage d´autres tailles de cames. Le seul inconvénient est un accès difficile au panneau de contrôle du tour, à cause de la position du robot.

Configuration #6

Cette configuration est très similaire à la configuration #5 dans l´organisation des machines. A la place d´un tour vertical, deux plus petits tours Doosan Puma V8300 sont utilisés et placés l´un a cote de l´autre. Un avantage de cette solution est que l´espace a été économisée et une livraison rapide des machines, en comparaison avec d´autres propositions. Le prix de cette solution est moins élevé que celui de la configuration #5, mais les machines ne disposent pas d´un convoyeur. En plus, le temps de manipulation est augmenté parce que chaque machine est utilisée pour l´usinage de seulement une partie de la pièce, comme dans la configuration #3. Un autre inconvénient est le problème avec la machine à marquer qui ne peut pas être implémenter sur le convoyeur, mais doit être placer séparément. A cause de ces complications, le robot est surchargé comme dans la configuration #3 ce que ralenti tout le processus de fabrication.

Configuration #7

Par rapport à toutes les configurations proposées, celle-là a une configuration des machines complétement différente, ce que change aussi le flux de la matière. Au lieu d´utiliser des machine d´usinages séparés pour chaque le tournage et le fraisage, des fraiseuses-tourneuses NT4250 de DMG Mori sont utilisés. Les machines sont beaucoup plus grandes et dans la configuration proposée doivent être opérés par un robot plus grand.

Trois de ces machines sont placées l´un a cote de l´autre et ils sont opérés par un robot IRB 6640 avec un rayon plus grand. Le robot charge les machines grâce à l´utilisation de la vision 3D, depuis des palettes qui sont amenées par l´opérateur. Cette configuration permet l´usinage de trois tailles de cames différentes en parallèle. Après la fin d´usinage, les pièces sont posées sur un convoyeur qui les transporte dans la deuxième partie de la cellule de production. Une machine de marquage est implémentée sur ce convoyeur et cette opération et automatisée. Quand les cames sont marquées, elles sont distribuées dans une de trois collecteurs dépendant sur leur taille. Un deuxième robot – IRB 4600 – est utilisé pour les charger dans des palettes pour le traitement thermique ou dans la station de contrôle. Le reste d´opérations ne sont pas automatisés.

Cette solution offre la possibilité d´usiner plusieurs tailles de cames en parallèle, mais un réglage comme ça n´est pas optimale. Les temps d´usinage changent dépendant de la taille de came, ce que mène vers une désorganisation de la chaine d´opération. Il est plus agréable d´usiner des tailles de cames semblables.

Grace au changement de du parc de machine complet cette proposition peut être le moins compliqué en relation avec l´organisation de la production actuelle. L´avantage est la diminution du temps de manipulation aussi que la diminution de nombre de montage des pièces ce que diminue les erreurs de précision causée par le montage mauvais. L´inconvénient de cette solution est la diminution de la productivité par rapport aux d´autres solutions proposées. Si on la compare avec la solution #5 qui a la productivité la plus élevée, elle sera seulement 30%. Malgré ça, ce n´est qu´une des facteurs et aussi les autres doivent être considérés pour faire un choix.

ANALYSE D´INVESTISSEMENT

Le facteur économique est très important, surtout pour des projets avec le temps de retour long. Dans les projets d´automation de la fabrication, le taux d´investissement augmente en raison directe avec la diversité des produits fabriqués [40]. Tous les prix mentionnés dans ce travail sont un valeur moyen, calculé à partir de plusieurs prix proposés par diverses entreprises. Cet analyse sert à montrer le taux d´investissement approximatif et non pas exacte, seulement les articles les plus importants sont inclus. Il y en a beaucoup plus, mais non pas une grande influence sur le prix finale et vont être traités dans les dernières étapes d´automation. Les prix mentionnés sont sans la taxe à valeur ajoutée.

Tab. 1 Le taux d´investissement de chaque

	#1	#2	#3	#4	#5	#6	#7
N. 1 [€]	411000	701000	975000	119000 0	146000 0	109000 0	2685000
N. 2 [€]	106100 0	148100 0	157500 0	189000 0	206300 0	187000 0	-

Tab. 2 Le temps de retour d´investissement pour chaque

	#1	#2	#3	#4	#5	#6	#7
Temps de retour N. 1 [ans]	11,8	10	14	17	21	15,6	38,5
Temps de retour N. 2 [ans]	30,5	22,3	22,6	27,1	29,6	26,8	-

Le tableau 1 montre le taux d´investissement calculé, plus détaillé dans la version complète. La ligne N.1 référé à la configuration correspondante en utilisant les centres de fraisage originels et la ligne N.2 correspond à la même configuration mais en utilisant des nouveaux centres de fraisage. Le tableau 2 montre le temps du retour d´investissement, qui sont assez élevés. Il est important de dire que ces temps ont été calculés en comptant avec l´épargne sur les salaires d´opérateurs. Le temps du retour d´investissement peut réellement être beaucoup plus court pour plusieurs raisons qui sont discutées dans la chapitre suivante.

DISCUSSION

La modernisation est l´optimalisation du processus de fabrication est un facteur important afin de garder la compétitivité pour toutes les entreprises fabricantes un produit. L´optimalisation du cycle d´usinage, l´élimination d´opérations secondaires et des épargnes financières sont la clé du succès. Les cycles d´usinage de la cellule de production discutée sont bien optimalisé pour les machine qui sont utilisées actuellement. Apres l´analyse du processus de production, certaines possibilités d´améliorations d´opérations secondaires sont proposées.

Ça pourra être l´amélioration du nettoyage des cames du liquide de refroidissement et des copeaux après le tournage qui peut être automatisé par l´installation d´un système de soufflage par de l´air comprimé. Il est aussi possible d´intégrer un marquer automatique sur le convoyeur. Ce nouveau marquer peut être un marquer laser avec le temps de d´estampillage plus court que celui utilisé actuellement. Ensuite il est possible d´utiliser un outil d´ébavurage spécial à la fin du cycle de fraisage.

Même si ce travail ne s´occupe pas de la deuxième cellule de fabrication dans laquelle sont installées les machines de finition des cames, ce processus a été analysé. Les deux rectifieuses ont une architecture similaire aux centres de fraisage dans la première cellule – ils ont une table rotative divisé en deux parties. Une de ces parties est à l´intérieur de la machine et la pièce est usinée pendant qu´une deuxième pièce peut être fixer sur la deuxième moitié de la table. La rectification peut être accélérer encore plus en utilisant une fixation capable de fixer deux cames en même temps. La meule qui est actuellement utilisée est assez longue pour usiner deux cames placées une derrière l´autre, les facteurs limitants sont la puissance de la machine et la flexion d´outil.

Sauf le taux d´investissement et le temps de retour d´investissement qui ont été discutées dans la chapitre précédente, d´autres facteurs important qu´il faut prendre en compte sont la flexibilité et le taux de modernisation amenés. La flexibilité corresponde à la possibilité d´ajuster les procédés de fabrications aux autres types de produits, mais aussi la difficulté d´ajustement pour des différentes tailles de cames. Ceci est important par exemple quand il y a un agrandissement de la demande d´une taille de moteur. La configuration #7 qui a le prix d´investissement le plus grand de toutes les configurations proposées, peut être un favori grâce à une grande flexibilité. Le taux de modernisation peut aussi influencer le choix de la configuration parce que les machines sont usées ce que mène vers la maintenance plus couteuse. En plus de la maintenance, l’âge des machines peut causer deux types de problèmes – le problème avec la communication avec des robots et des logiciel d´automation et les problèmes de sécurité. Surtout le deuxième peut être inattendu, car les normes et les règlements changent chaque année. Les machines ont été adaptés aux normes actuelles de l´époque quand ils étaient construits, mais comme la cellule de production doit conformer les normes comme un ensemble, les machines doivent conformer les normes actuelles.

CONCLUSION

La thèse a été élaborée directement dans le milieu industriel et discute des options réellement existantes. Elle a été modifiée plusieurs fois et adaptée aux problèmes rencontrés, avant de proposer des solutions différentes. Chaque solution contient un graphique de toutes les opérations avec leur description détaillée et des avantages et inconvénients relevés. Chaque configuration contient des images de son 3D model et une partie de Gantt graphe avec un commentaire.

Les configurations proposées varient et sont différente une de l´autre, afin de montrer la variabilité de la solution finale. Grace à l´intégration d´éléments d´automation et de machines d´usinage différents, divers problèmes ont été découverts. Ces problèmes peuvent être discuté dans l´entreprise elle-même, ou avec des entreprises externes afin d´obtenir une solution optimale. La thèse contient aussi une simple analyse d´investissement, pour montrer le taux d´investissement approximatif.

Automation de la production dans une usines déjà activement fabricante des produits est un problème complexe qui demande une planification détaillée. Le temps de retour d´investissement calculé parait comme un obstacle qui puisse bloquer la réalisation de ce projet. Le plus grand problème d´un haut prix d´investissement est la nécessité d´une grande flexibilité de production. Pour que le projet puisse être réalisé, il faut se concentrer sur une haute productivité de la cellule de production. Une productivité plus haute signifie plus de gain, et plus de gain signifie le temps de retour d´investissement plus court. Basé sur ça, il est recommandé de développer plus les configuration #4, #5 et #6 qui ont la plus haute productivité des solutions proposées. Avec le prix de la vente d´une came estimé à 50€, l´augmentation de la production de seulement 5% par jour va diminuer le temps de retour d´investissement a 5 ans, au lieu de 21 pour la configuration #5. En ajoutant le prix de l´espace économisé et le facteur de la modernisation du parc de machine, le projet devient réalisable.

Le travail regroupe et résume les informations sur l´automation d´une cellule de production flexible et peut être utile pour différents entreprises, commençant avec un projet d´automation. Elle confirme qu´une configuration idéale doit être productive et doit occuper le moins d´espace possible. En même temps, elle montre qu´il ne faut pas avoir peur d´investissements plus hauts. En cas idéal, il faut essayer de réaliser une cellule de production complétement nouvelle et d´utiliser des machines originales aux autres objets d´utilisation.

Ensemble avec les autres informations dans toutes le chapitres, la thèse sert comme un source d´informations de base sur l´automation des lieux de travail. Ces informations peuvent être communiquées avec les autres filiales de PH et faciliter le début des projets d´automation.

ABSTRACT

The objective of this work is to analyze the current production process of the cams within Poclain Hydraulics and to propose its optimizations. After that, a market research of the possibilities of automation is done. Based on the analysis of the production process and the market research, various configurations of an automated production cell are to be proposed. This work deals with a technical and economic analysis of the problem and compares the different possibilities of automation of the production.

Key words

Automation, robotization, production cell, investment analysis

BIBLIOGRAPHIC CITATION

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DECLARATION

Prehlasujem, že som diplomovú prácu na tému **Implementation of automation elements within machining processes in Poclain Hydraulics s.r.o.** vypracoval samostatne s použitím odbornej literatúry a prameňov, uvedených na zozname, ktorý tvorí prílohu tejto práce.

Date	Bc. Martin Ciba

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CONTENT

INTRODUCTION

This thesis was created in collaboration with Poclain Hydraulics s.r.o. (further noted as PH), world leading specialist in hydrostatic transmission. The company is originally based in Verberie, France, and has several branch establishments around the globe. The analysis of the fabrication process and all propositions are related to the plant in Brno, Czech Republic.

This work deals with automation and robotization of a production line focused on fabrication of the cams. The cams are the critical parts of the hydrostatic motors working under difficult conditions such as elevated temperature and constant mechanical contact with the rotating part of the motor.

The work is divided into several parts: literature research, the analysis of the current fabrication process, propositions for the automation of the production cell, a simple economic analysis of the proposed solutions, discussion and conclusion.

The objectives of this work are to analyze the current situation and to propose solutions for automation and robotization. The aim of automation in this case is to provide financial savings, to simplify the operators´ work and if possible, to improve the production rate. The whole process consists of several machining and heat treatment operations and the different cams can be produced in small series ranging from only several pieces to several thousands of parts fabricated per year. Unlike in the production of big series, the automated production cell should be flexible and easy to adapt to the production of different types of cams.

1 LITERATURE RESEARCH

With the increasing rate of commands, the production has to rise in order to keep the customers satisfied. In a developed company with many years of experiences on the market and a well-protected fabrication know-how, it is necessary to constantly evolve, find new solutions and improve the technologies. This means also to optimize the production and implement new technologies, such as automation elements.

A perspective option is to use robots for the repetitive actions such as loading/unloading of the machine and other manipulation with the products. This would lead to a relief for the operators and the improvement of the precision and work speed. The other automation elements such as conveyors, automatic measurement stations and integrated circuits should be considered and compared with the non-automated solutions.

1.1 Hydraulic motors

A hydraulic motor is a mechanical actuator that converts hydraulic potential energy into mechanical rotary power. Basically, the hydraulic motors are divided into high-speed and low-speed motors. Depending on the type of construction there exist gear motors, vane motors and piston motors. Depending on the type of use they can be sorted into bidirectional and unidirectional motors, both with fixed or variable displacement. The motor displacement is the volume of fluid required to turn the motor shaft for one complete revolution.

All types of hydraulic motors work on the same principle, they have a driving surface area subject to a pressure differential and a way of timing the porting of the pressurized fluid to the pressure surface. Thanks to this and a mechanical connection between the surface and an output shaft a continuous rotation is achieved [1].

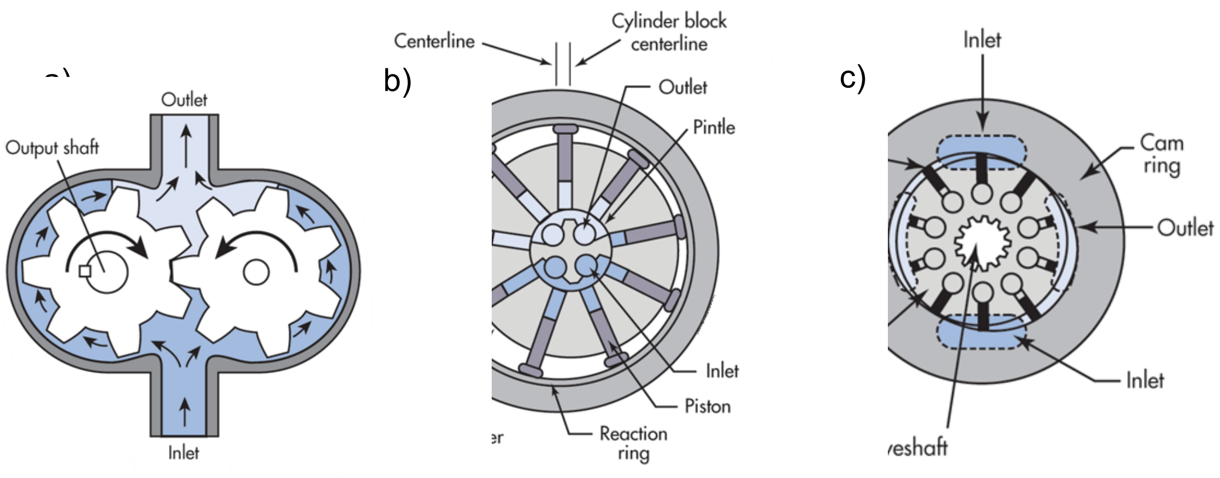


Fig.1 Basic types of hydraulic motors depending on the type of construction: a) gear motor, b) vane motor and c) piston motor [2].

1.1.1 Radial-piston hydraulic motors

The radial-piston motors have a cylinder barrel that contains several pistons that reciprocate in radial bores thanks to a pressure fluid. The barrel is attached to a driven shaft, the pistons push against the cam ring and the reaction forces rotate the barrel.

These types of motors are very efficient, due to this a high degree of precision is required during the machining and other manufacturing operations. They have a very wide application in the mobile hydraulic systems, especially in the hydraulic transmission. This leads to increased initial costs which are compensated by their long life, they usually provide high torque at relatively low shaft speeds [2].

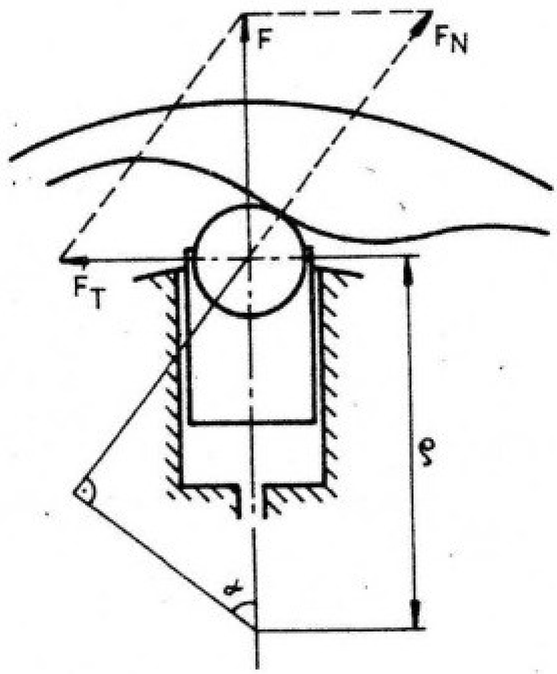


Fig.2 Resolution of the forces in the radial-piston hydraulic motor [4].

Cam-type radial-piston motors consist of a cam ring, a cylinder-carrying rotor, a fluid distribution shaft and several pistons and roller sets. When the rotor makes a turn, the cam ring pushes the piston. The ports for inlet and outlet of the fluid are located in the shaft, to deliver pressurized fluid to the extending pistons and to create a turning torque. The fluid is then discharged for the retracting pitons to allow the rotor to continue the rotation.

The concentric configuration of the motor provides a balanced radial force, so the motor starts quickly and operates smoothly under very low speeds. The disadvantage is a slightly lower overall efficient performance comparing to those of an eccentric configuration [2].

1.1.2 Cam

The cam is a static part of the torque module of a hydraulic motor with a defined geometry and high requirements on the surface integrity. It is considered to be the "critical part" of the motor as it is subjected to high stresses due to the mechanical contact with the pistons and to the elevated work temperatures. It is made of several internal cam-lobe curves and the efficiency of the motor depends directly on the curve geometry of the cam. The geometry is defined for each type of motor depending on its application [3].

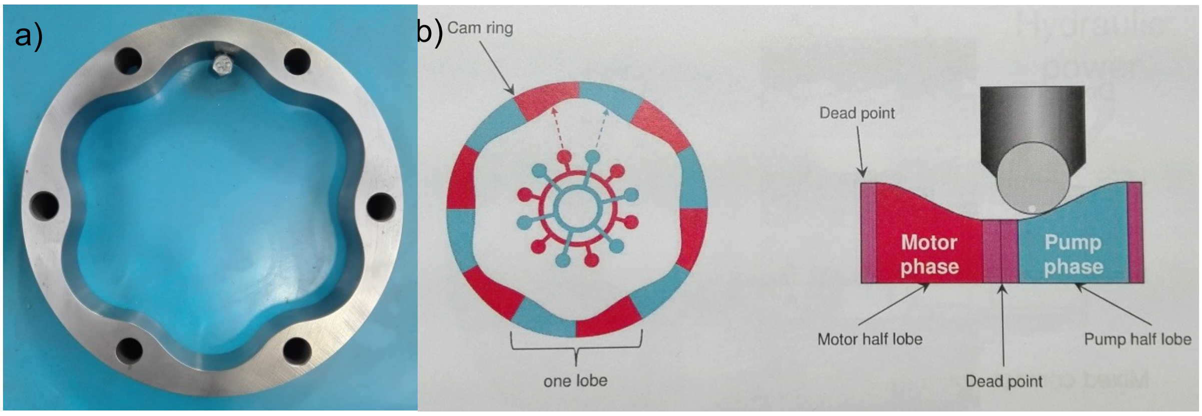


Fig. 3 a) An example of a cam fabricated in PH and b) Schema of the cam with working phases [3].

1.1.3 Motor MS

The cams this thesis deals with are designated for the MS range motors fabricated in the plants in Czech Republic, USA and France. The advantages of this type of motor are: the direct drive – no mechanical reduction and high efficiency, the low speed – a quiet working mode, the low inertia and an easy stop & go or reversion, the constant torque and speed and the adaptability on several bearing supports and other types of mounting. The motor´s working pressure is 450 bars.

Tab.1.1 Basic technical parameters of the different MS motor ranges [3].

Parameter \ Type of motor	MS02	MS25	MS125
Displacement range [cm³/rev]	172-255	2004-3006	10000-15000
Max torque [Nm]	1800	21500	77000
Max speed [RPM]	590	145	50
Max power [kW]	18	90	240

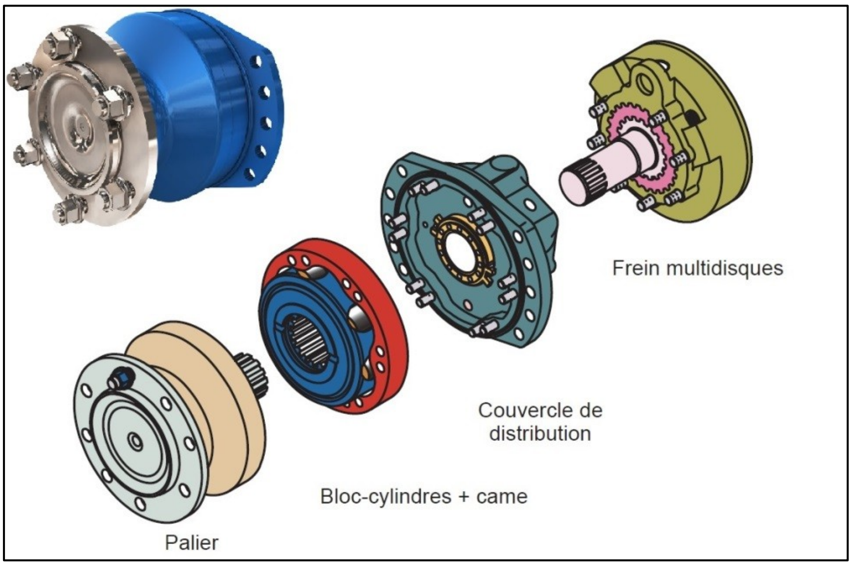


Fig.4 Illustration of the assembly of a MS02 hydraulic motor fabricated in Brno [3].

1.1.4 Operating parameters of the hydraulic motors

The theoretical output torque is defined by the following equation [1]:

$$T = \frac{D_v}{2\pi} \cdot \Delta p \tag{1.1.1}$$

This theoretical output torque does not take into consideration the mechanical losses, but in practice it is impossible to get the theoretical torque from the motor. To define the real output torque terms breakaway torque and running torque are often used. The breakaway torque represents the amount of torque needed to get the stationary motor turning – the amount of torque needed to overcome the static resistance. The running torque refers to the amount of torque needed to overcome the dynamic resistance of the motor, to keep it running. Normally, the starting torque for most hydraulic motors ranges between 70 and 80% and the running torque is approximately 90% of the theoretical torque. Mechanical efficiency is used to quantify the ratio between the actual torque deliverable to drive a load and the theoretical torque [1]:

$$\eta_m = \frac{T_A}{T} \tag{1.1.2}$$

The theoretical output speed of a hydraulic motor is defined by motor displacement and the supplying flow rate to the motor [1]:

$$\eta_o = \frac{Q}{D_v} \tag{1.1.3}$$

The theoretical output speed of a motor is defined as the motor speed generated without any flow losses during the process. It is impossible to achieve the theoretical output speed due to the unavoidable fluid leakage within a hydraulic motor. Therefore, the volumetric efficiency is defined as the ratio of the theoretical flow over the actual flow required to produce a certain speed [1]:

$$\eta_v = \frac{Q_T}{Q_A} \tag{1.1.4}$$

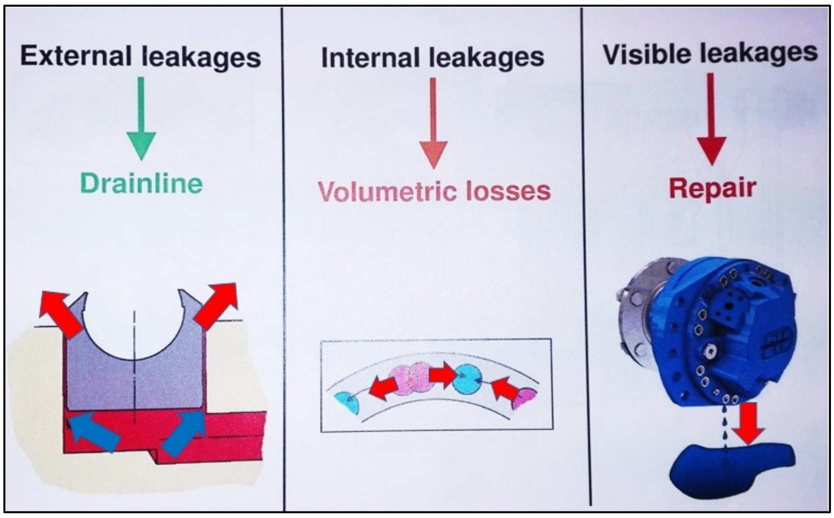


Fig.5 Examples of possible fluid leakage [3].

1.2 Hydrostatic transmission

Basically, the hydrostatic transmission (HST) is a coupled pump-motor system that transmits the power from the principal mover, often an internal combustion engine, to the final drive. Compared to other types of transmission like mechanical and electrical for example, the main advantage of the HSTs is the possible variability of power and torque using the variable/fixed displacement pumps and motors and their configuration. However, the price for these possibilities is lower efficiency. For example, typical mechanical transmission efficiency for the same application is 92% compared to 80% for the HSTs [1].

Having been constructed by a pair of hydraulic pump-motors, an HST is normally sized in terms of system corner power, that is defined by the maximum force and maximum speed needed to perform a certain function. The corner power required to move the vehicle can be determined using the following equation [1]:

$$P_C = \frac{F_t \cdot v}{\eta_O \cdot f} \tag{1.2.1}$$

To convert this mechanical corner power into a hydraulic form, the following equation is used [1]:

$$P_h = \frac{\Delta p \cdot Q}{\eta_O} \tag{1.2.2}$$

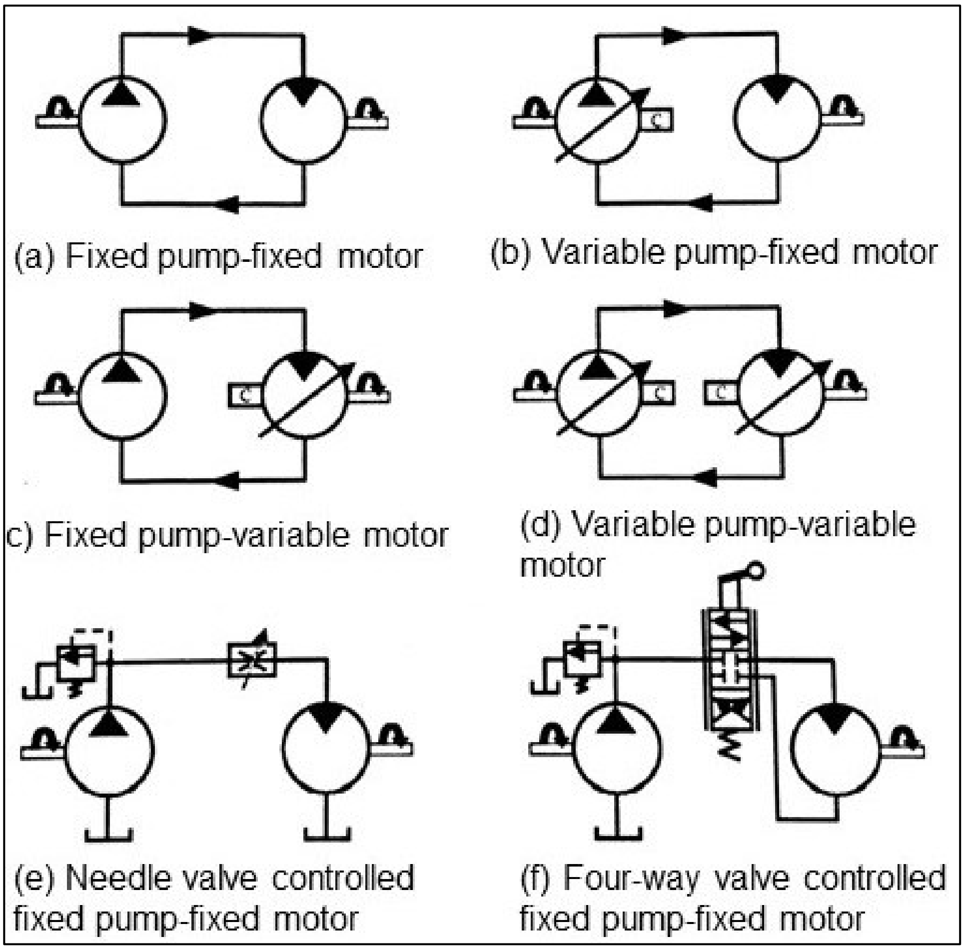


Fig.6 Conceptual illustration of six typical configuration arrangements of hydrostatic transmission [1].

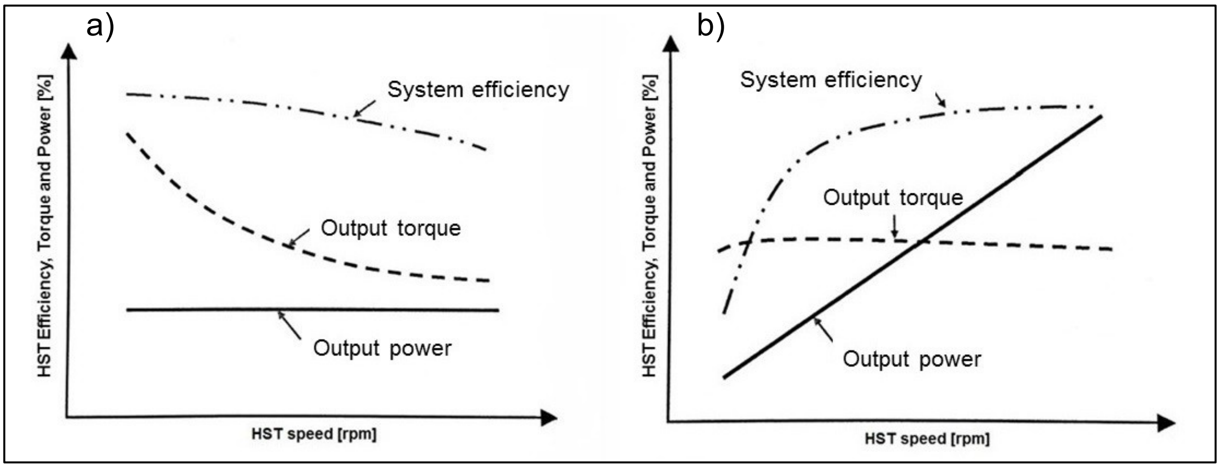


Fig.7 Typical performance curves of a) fixed pump – variable motor and b) variable pump – fixed motor [1].

1.3 Application of hydrostatic transmission

PH has become the world leader in hydrostatic transmissions thanks to the high-performance cam-lobe radial-piston motors. Beyond the off-road vehicle market expertise, today they offer innovative solutions through hydraulic hybridizations. It has been used in widely various mobile power transmission systems such as agriculture, construction, forestry, on-road applications and industrial applications.

Flexibility in design, compactness in size and high power-to-weight ratio are the major advantages that make HSTs well suitable for being used in mobile machinery. Such machines require delivery of engine output power to actuators at various locations and normally have limited space between the power source and the power consumers. In addition, this system of transmission provides overload protection by stalling under excessive load and opening the line-relief valve to avoid damage to the tractor.

There exist 4 common designs of HSTs, from which the split design is the most used as it allows the use of one pump to drive multiple motors. Thanks to the low-inertia of hydraulic power transmissions, the split configuration allows coupling the pump directly to the engine without adding much starting torque to the engine. This can considerably simplify the design of a tractor power train and result in important weight and cost reductions [3].

Fig.8 Examples of different applications in agriculture, underground mining and on-road [3].

1.4 Automation

Automation is the phase of the technical evolution, which is characterized by realization of manufacturing and other processes without the direct intervention of humans, however they are still supervising the process. It started in the early twenties of the twentieth century with the discovery of modern calculation systems. Automation is the usage of different technical elements for the self-acting parts of the process or for the whole processes, but strictly following a before designed program. In higher forms of automation, the work-pieces are automatically controlled and based on the control results the process can be automatically adjusted – there is a feedback on the fabrication process. Using of automation leads to a higher productivity, lower expenses and less errors in the production [6].

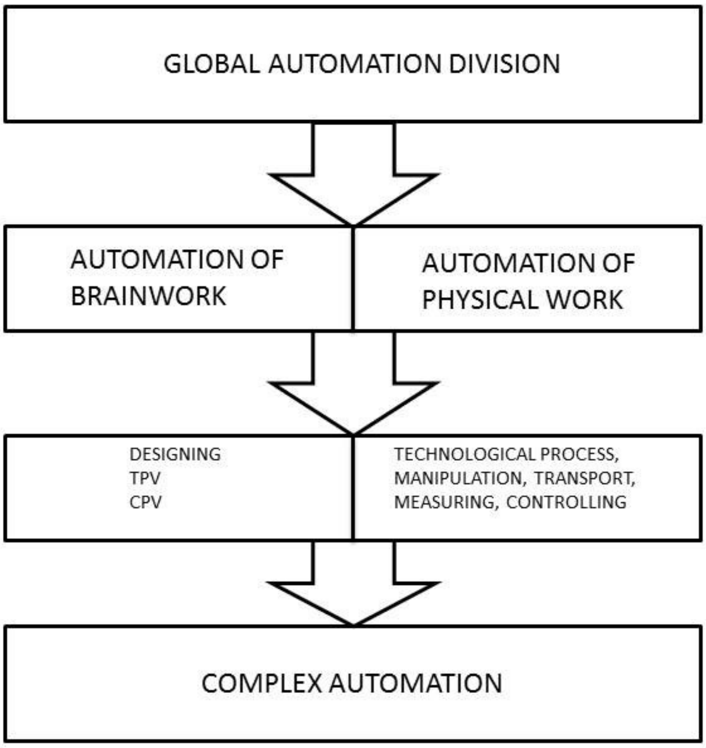


Fig.9 Schematic layout of the global automation division [6].

The results of automation of brainwork are the following:

- higher precision of output standards,
- ability to optimize the manufacturing methods,
- operative planning of production,
- objectification of the standards,
- higher level of organization of the manufacturing process [6].

The results of automation of physical work are the following:

- reduction of losses caused by fluctuation of employees,
- elimination of impact of fatigue of the employees,
- diminution of physical effort and repetitive actions,
- reduction of specific cost of the product,
- improvement of the work safety and hygiene [6].

Human intervention in automated process except supervising is execution of secondary operations that are ineffective or too difficult for automation. Typical example is grabbing of a freely lying part with a complicated geometry and it´s insertion into the machine. This is often the most complicated part of the automation process. The easiest solution is to bring the parts to an exact place already well-oriented using a conveyor. A modern solution can be proposed – use of 2D or 3D vision, however this technical solution is rather expensive [7].

1.4.1 Manufacturing system

A manufacturing system is any fabrication unit that can be considered as isolated. For example, it can be a workshop or a production plant, if we can consider them as relatively isolated. Manufacturing systems with mutual relationships can be considered as higher production systems. Therefore, it is practical to divide them according to the size and internal complexity.

Basic elements of the manufacturing systems are the workplaces. A machining center with circular tool exchanger and automated pallet exchanger can be considered as a workplace for example. If the majority of the workplaces and the transport between them are automatic, control of such workplace is highly automated so the operator is mostly supervising and solving unexpected situations, it is considered as an automated fabrication system. The fabrication systems are divided into two large families regarding the production character – solid and flexible automation. In the case of a solid automation, the machines and production lines are highly productive but do not allow the fabrication of several types or sizes of the product. In contrary, the flexible automation has lower production rate but allows the adaption to different types and sizes of products [5].

Classification of the production lines according to the degree of flexibility:

- conventional solid production lines – they allow the production of only one, maximally 2-3 types of parts with similar dimensions that are known in advance, during the concept of the production line;
- adjustable production lines – they allow the production of several types of parts with similar dimensions, the adjustment is manual or semi-automatic so it is not very effective to adjust more than 1-3 times a month;
- flexible production lines – they allow the production of different types of parts, the adjustment is automatic [5].

1.4.2 Flexible manufacturing systems

Flexible Manufacturing Unit (further noted as FMU) consists of one machine, usually a machining center capable of at least semi-automatic work. Flexible Manufacturing Cell (further noted as FMC) consists of two or more machines, usually machining centers, all functions are computer controlled. Flexible Manufacturing System (further noted as FMS) consists of two or more FMCs that are connected with automated transport system carrying pallets, parts and tools from the warehouse to the machines; it is a computer controlled integrated complex of CNC workplaces with minimal human intervention and minimal needs of adjustment able to produce the parts following a predefined plan. FMS allows automatically produce and manipulate with the parts in a small or mid series, but is greatly more expensive than the conventional manufacturing line. In the case of a transition from a conventional manufacturing to the flexible automated manufacturing, a continual transition depending directly on the financial and technical possibilities proves to be convenient. Every step of atomization has to ensure a functional manufacturing system capable of making profit for the next step of automation [5].

The flexibility of FMS is characterized by several properties:

- flexibility of the machine (adjustment of the machine considering the tools, fixture, setting of the part, NC program etc.),
- flexibility of the manufacturing process (ability to manufacture certain defined parts in random series),
- flexibility of the parts (ability to quickly and economically change the type of produced parts),
- flexibility in case of unexpected failure of any part of the system (ability to maintain the production even at lower rate),
- flexibility of the produced volume of parts,
- flexibility of additional extension of the automation,
- operative flexibility (ability to change several consecutive operations for each produced part) [5].

The development of FMSs is supposed to allow rentable and operative manufacturing of even small batches of products. Integration of all parts of manufacturing, such as machining, manipulation, measuring, cleaning, stocking and tool manipulation leads to following advantages:

- more operative reaction on market demands,
- better product quality,
- reduction of the production time,
- reduction of labor consumption,
- higher efficiency of machines,
- reduction of stock of the material and tools,
- better production management [5].

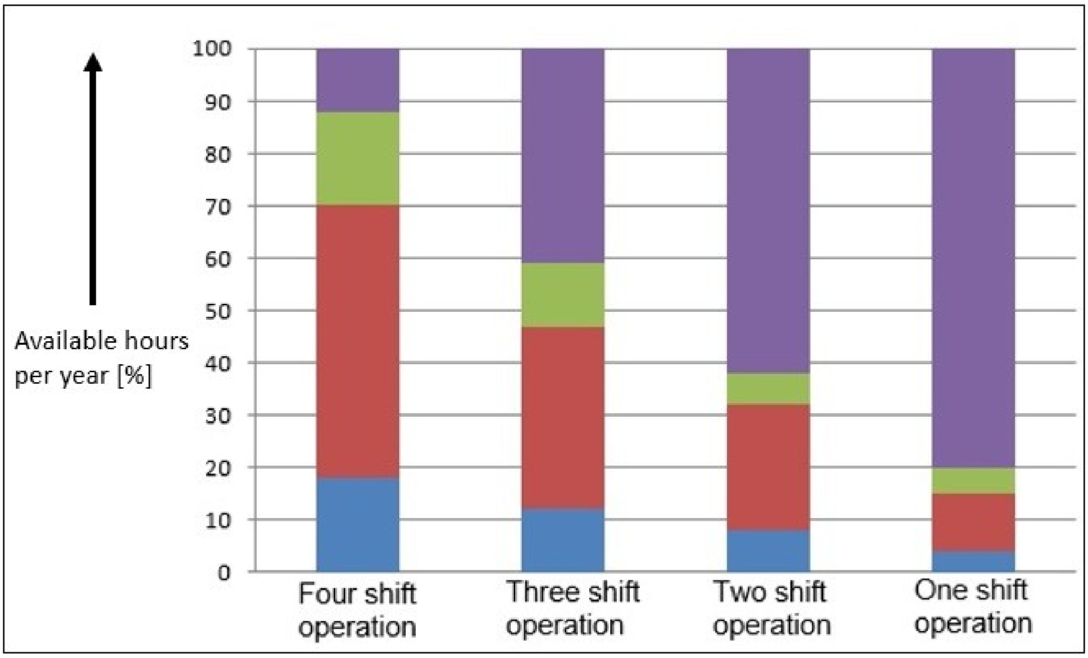


Fig. 10 Influence of the number of shifts on the extensive utilization, where 100 % represents 8760 hours per year. The blue color represents the time of machining, in red is the time of manipulation, in green is marked the idle time and in purple is the time of inactivity [5].

1.5 Robotization

Robots have rapidly evolved from theory to application in the 1970´s, primarily due to the need for improved productivity and quality. Increased productivity is the most important benefit of industrial robot application today. Manufacturers will adopt robots which can work 24 hours 7 a week at a fraction of the cost of a non-automated production line. Consistent quality resulting from precise repetition is another important benefit. Robots are not subject to boredom, carelessness, fatigue or emotion so they are perfect for repetitive industrial operations, as well as for operation in dangerous work conditions. Another key feature of the robots is their versatility, since it can be reprogrammed for different operations and to use different end effectors.

In evaluating potential applications, it is necessary to account for performance requirements such as cycle times, parts tolerances and layout requirements. In addition, the product characteristics and process modifications must be considered. It is also necessary to review the requirements for payload, reach, stroke, memory, complex programming, controls flexibility, human factors, maintenance skills and cost [8].

1.5.1 Industrial robots

In the literature, industrial robots are machines able to accomplish different manipulation tasks. They are officially defined by the norm ISO 8373:1994 [9] as: “Automatically guided, programmable, multitask manipulator for action in 3 or more axis.” A manipulator is a machine with two-position self-drive movement unit and guidance for automatic manipulation with the work-pieces, following a defined program and time schedule in accordance with the operations of manufacturing machines. Robots can be equipped with different tools, grippers or other instruments for manipulation, technological or assembly operations. They are characterized by, fast and reliable work, improvement of the effectiveness and work productivity, high precision and quality and replacement of hard physical work [9].

Main functions of industrial robots are:

- capability of manipulation – the ability to grip, transfer, orientate and position the objects;
- versatility – robots are not single-purposed, after a change of program and the end effector or tool it is possible to use it for various applications, under different conditions;
- perception – the ability to perceive the work environment using internal and external sensors for to respect the programmed conditions;
- autonomy – the ability to independently execute required order of functions following a predefined program, moreover to have a certain level of self-decision;
- integrity – the ability to integrate several function groups and main subsystems into one [9].

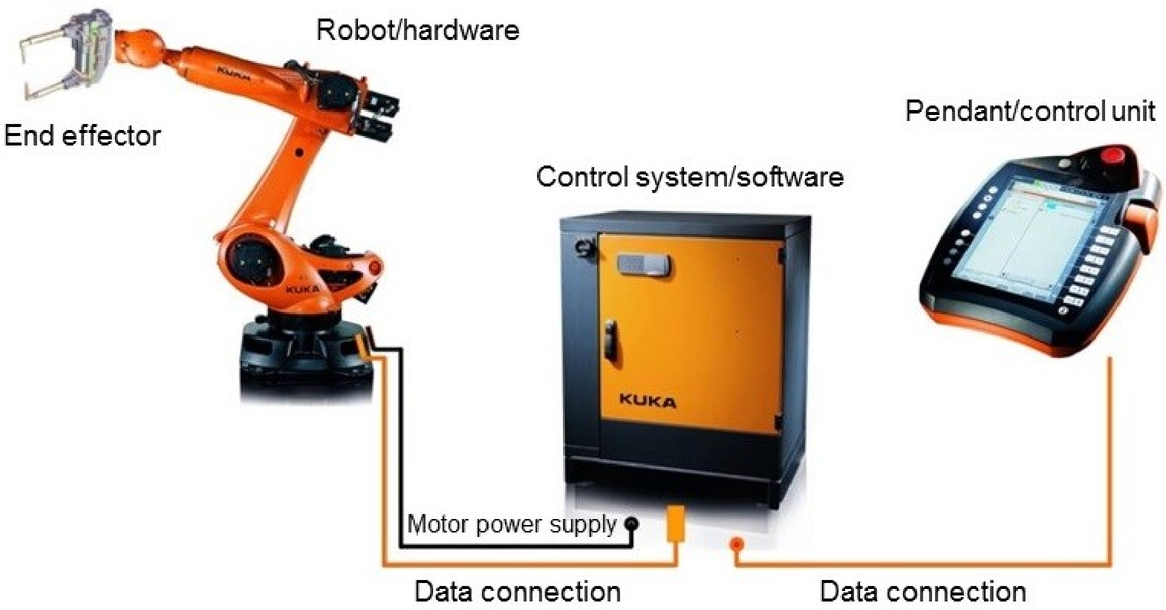


Fig.11 Example of a typical structure of an industrial robot composed of hardware, software and a control unit [9].

Mechanical part of industrial robot is composed from arms and joints. Joints are assuring the movement and the arms are the solid connections between them. Every joint serve as one axis of rotation – or a degree of freedom, typically the robots have 6 degrees of freedom.

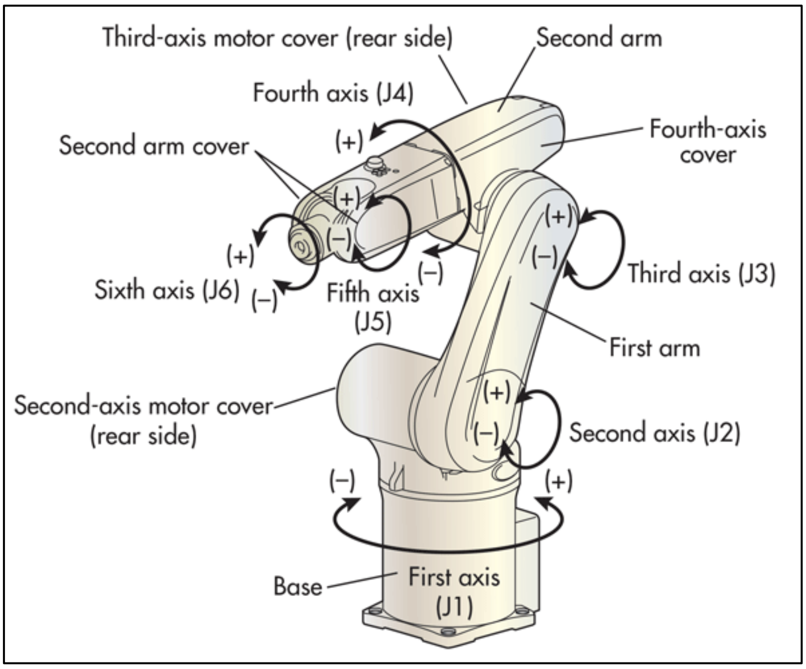


Fig.12 Schematic layout of the mechanical structure of industrial robots [10].

The end effector is a separate part of the robot and serves for gripping of the object by a gripper or as a tool holder. Together with the robot it participates on the positioning and orientation of the object. Depending on the function it is divided into grippers, heads, integrated effectors and tools.

The control system reads the information from the memory of the controlling computer as well as the information from the sensors, and depending on this information pilots the robot movement. It includes all the positioning functions of the robot and the piloting of other peripheral systems. The piloting is a complex of microprocessors working according to a multitasking method and it is possible to process several actions at the same time. The control unit is usually equipped with a display showing current operation or at least a status line and a switch between automatic and manual operation of the robot. On the sides of the control unit are placed the functional keys for speed control, choice of the coordinate system etc. The pendant involves the keys for manual control of the robot in every axis and a security central stop button [9].

2 ANALYSIS OF THE REQUIREMENTS FOR AUTOMATION

Automation of a production line is a complex engineering problem that requires rigorous planning. It is a long-term investment with the payback time of several years, therefore there is no room for an error. Automation often changes the layout of the workplace, which means it changes the flow of the material as well. The changes concern many different departments and employees, from operators who have to adapt to the new working conditions and different operations, to managers who have to consider the differences and innovations to assure the best company profit.

There are many demands, regulations and technical specifications applying to the production line that need to be complied. Here belongs the domain of quality, effectiveness, safety, environment and many more company's internal specifications. The company has an internal regulation defining the general specifications for automation of a production line in any group plant anywhere in the world which has been created by the PH engineers from the plant in the USA. This regulation will be applied to a specific case that is the automation of the production line of the cams manufactured in Brno, Czech Republic.

2.1 Current manufacturing process

The manufacturing process consists of buying a semi product from a supplier and then machining it to the specified dimensions respecting different geometry tolerances, such as flatness, perpendicularity, parallelism or total run-out. The applied machining operations are turning, milling, heat treatment, grinding and honing and they take place in two separate manufacturing cells. Only the first one is planned to be automated, so the two super finishing operations - profile grinding and honing – located in the second cell will not be discussed.

The complexity of the manufacturing process is emphasized by the fact that there is fabrication of different sizes and types of the cams on the same production line. Therefore, the machines should be prepared for machining of these different types of product, or adjusted for each type every time there is a change of fabrication, which can be a couple of times a day. The machines are optimized for the production of 4 different cam sizes, which means the adjustments of the machines are minimal to reduce the idle time and to simplify the work for the operators, however the time of adjustments cannot be omitted.

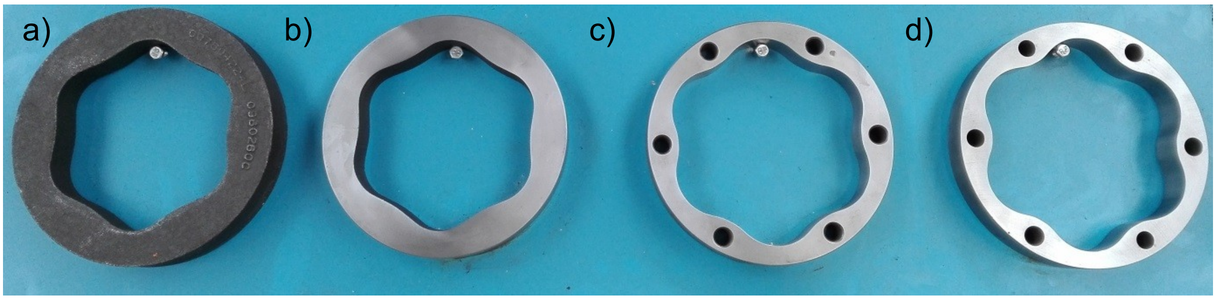


Fig.13 a) The bought semi-product, b) work-piece after turning operations, c) work-piece after milling operations, d) work-piece after finishing operations.

2.1.1 Turning

This is the first operation and is composed of 2 machining operations. The cam is moved to the designated position by a conveyor, which is loaded manually. The machine is a two-spindle vertical lathe, so each spindle can execute separate operations at the same time. The first operation is the machining of one radial surface and the axial surface of the cam. After that, the cam is moved to the second spindle where the second radial surface is machined. The part is then dropped on second conveyor and proceeds to the next operations.

2.1.2 Milling

After being marked with a QR code, each work piece is deposited into a box and is waiting for the second machining operation. They are being manually clamped by 2 or 4 pieces, depending on their size, onto a fixture and machined by one spindle during 1 machining cycle composed of roughing, finishing and drilling. There are two machines working in parallel, each has a rotating table with a reversible fixture, which allows 4 different products to be machined without changing the clamping fixtures. However, one side of the fixture is used for clamping different size of the work pieces on each of the two machines as shown on figure 14.

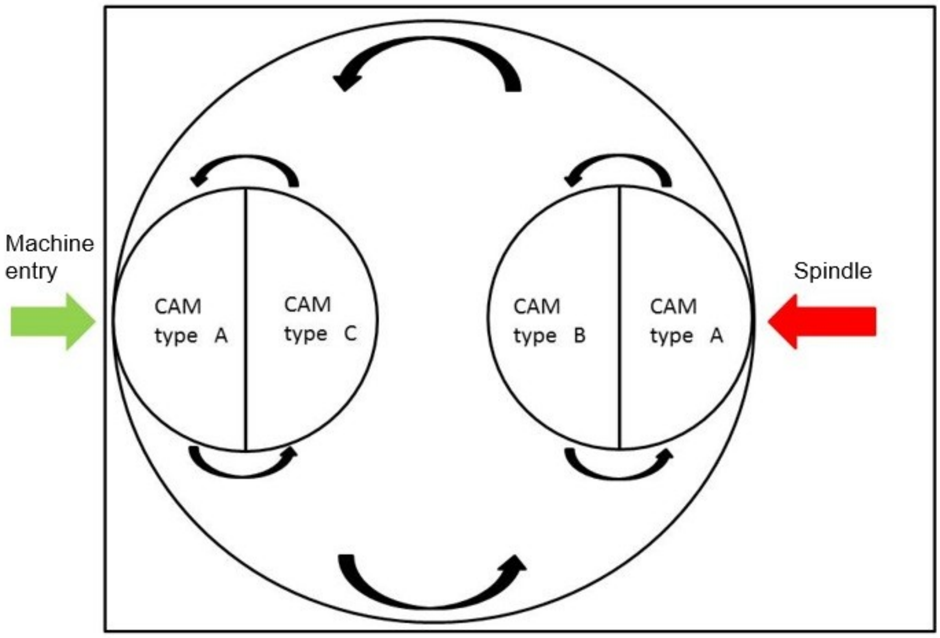


Fig.14 Schema showing the rotating table of the milling machine with a prepared typical configuration for 3 different sizes of the cams. The green flash represents the input side and the red flash represents the machining side.

The precision of this is operation is very important as the form of the leading curve is being created. The resolution of the pushing force of the piston depends directly on the curve geometry and the surface conditions influence the lifespan of the whole engine. Deburring is also a part of the machining cycle, the cams are then unclamped by to operator, any sharp edges are smoothed and the work piece is either put in a box or directly deposited on a palette for the next operations.

2.1.3 Heat treatment

This is a long-running operation that requires several hours to be completed, so usually the palette of work-pieces is relatively big with up to 100 pieces per palette. Loading of the palette is a manual operation and consists of loading of the work-pieces onto a designed bar and separating them with a centering ring. The rest is a semi-automatic operation, after the palette is fully loaded by the operator and brought to the designed palette lifter, the heat treatment station automatically takes it in. The whole operation is controlled by designed employees and after the carburizing, quenching and tempering are finished, the palette is automatically taken out.

It is important to note, that certain size changes of the work piece occur during the heat treatment operations. Here is a brief statement of the reasons of dimension changes, however it will not be discussed in details as it is not the objective of this work. It is needed to begin by considering the annealed state in which the microstructure consists of ferrite and cementite. Several reactions occur during the hardening. On heating to the austenitizing temperature, formation of austenite and the solution of cementite take place. On cooling from austenitizing temperature, the austenite may transform to martensite, lower bainite, upper bainite, or pearlite depending on the rate of cooling. Dimensions of heat-treated parts undergo changes because of an uneven temperature and structural phase transformations [11].

2.1.4 Rectification

The last operation of the first manufacturing cell is the rectification of the axial surfaces. The work pieces are manually loaded onto the machine by five to eight and the grinding itself is divided into two parts – they are identical for the two sides of the cam. The main interest of this operation is to reduce the dimensions error after the heat treatment. The variance due to the heat treatment can be predicted by the metallurgists and the rectification process is adjusted to obtain the specified quotes. As the cams during the rectification are fixed by a magnetic field, it is necessary to demagnetize them afterwards before passing them to the next operations.

2.2 Material flow analysis and specifications on the layout

2.2.1 Layout

One of the main problems of upgrading an already operating factory is the space restriction. An operating factory has a certain fixed layout, which divides the available work space into different sections regarding the current needs. The layout is usually optimized to obtain a good material flow, with as few as possible WIP areas. In this case, the machining hall is divided into fabrication cells for different types of products. To keep the investment price of the automation as low as possible and to slow down the production minimally, all the manipulation and layout changes will be made only in the area of the first cams fabrication cell.

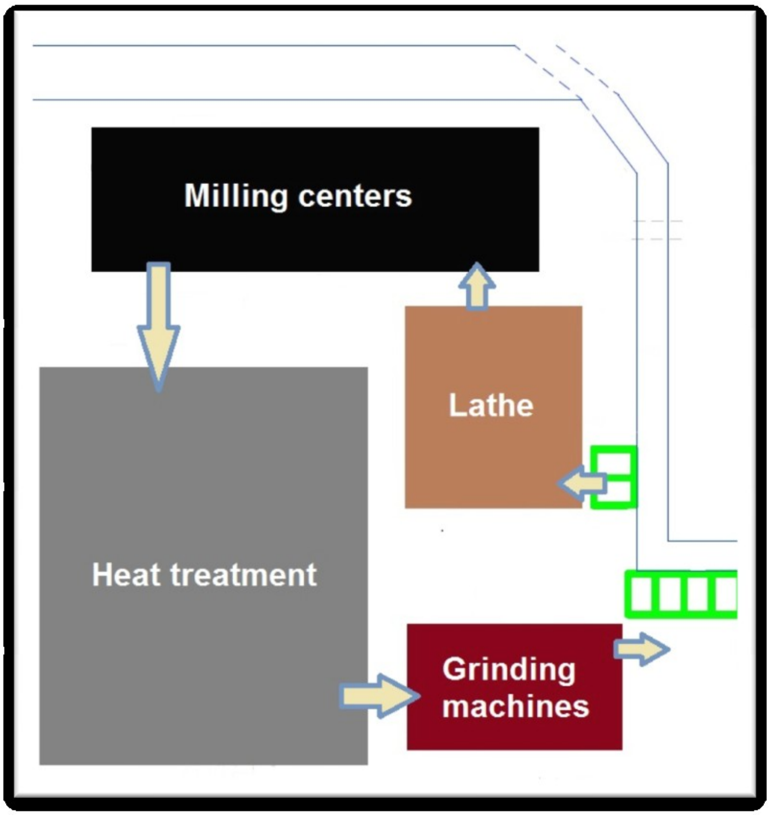


Fig.15 A simplified version of the current layout of first cam fabrication cell [3].

Any layout changes are limited by the maximal dimensions calculated in the equation (2.2.1), as well as by the position of the thermal treatment station which is fixed and its repositioning would be excessively expensive. Another important limitation would be the safety fence which must separate the area of the robot´s and the operator´s workplace to avoid any potential accident. A detailed analysis of the production process, workflow and VSM is necessary for choosing of the future layout. The production process normally divides into 4 main types of the layout – fixed position, product oriented, process oriented and cell layout. The process orientated and cell layout will be discussed below, as they fit the best the requirements of the company.

2.2.1.1 Process orientated layout

This organization is often reported to be suited when there is a wide variety of product, especially when the production process is organized in batches. It is also characterized by the fact that:

- the personnel and equipment to perform the same function are allocated in the same area,
- the different items must move from one area to another one, according to the sequence of operations previously established,
- the variety of products to be produced will lead to a diversity of flows through the facility,
- the variations in the production volumes for short periods of time may lead to modifications in the manufactured quantities [12].

If this type of layout is compared to the product oriented layout, the material handling and operations efficiency is lower. Therefore, the aim is to increase the operations efficiency and reduce the material handling costs. When gathering the information, it is important to know the demand forecast, the production plan, the working hours and the number of workers. To calculate the working area space, the following equations are used:

$$S_t = S_e + S_g + S_v \tag{2.2.1}$$

$$S_g = S_e \cdot n \tag{2.2.2}$$

$$S_v = (S_e + S_g) \cdot k \tag{2.2.3}$$

In these equations, S_t is the total available workspace, S_e is the static area which is the physical space for equipment and workstations, S_g is called gravitation area and includes the allocation of tools and materials n is the number of accessible sides, S_v is the space that allows operators and material movement and k is the factory coefficient. After applying the real numbers, the obtained result of the total available workspace is 391.05 m^2. It is also important to know the material flow among the departments or areas, distances among them and means of transportation [12].

2.2.1.2 Cellular layout

It is a group of equipment and workers that perform a sequence of operations over multiple units of an item or family of items. It applies the principles of so-called Group´s Technology to Manufacturing, these are grouping the outputs with the same characteristics to families, and assigning groups of machines and workers to produce each family. At the same time, it is essential to perform an internal layout of the cell. It is necessary to determine which condition allows the family grouping, in this case it will be the similar manufacturing routes. The products produced in the cell are the cams of the same type but of different size [12].

There exist different types of layouts called mixed layouts. For example, a group layout is a compromise between the product and process layouts, while using a group technology. Mixed layouts are often used thanks to a reasonable compromise between the production volume and the number of different products, as shown in fig. 16.

2.2.2 Material flow

Defined as a description of the transportation of all types of materials as a flow of entities, this term applies especially to modeling of a supply chain management. Industrial material flow is usually very complex with lots of different considered parameters. Various simulation programs were developed and still being improved to simplify the material flow analysis [13].

2.2.3 Material flow analysis (MFA)

MFA is a method to describe the metabolism of the anthropogenic and geogenic systems. These systems are explained as a group of linked processes with a certain objective. For example, a human body or a factory can be considered as an anthroposphere [13].

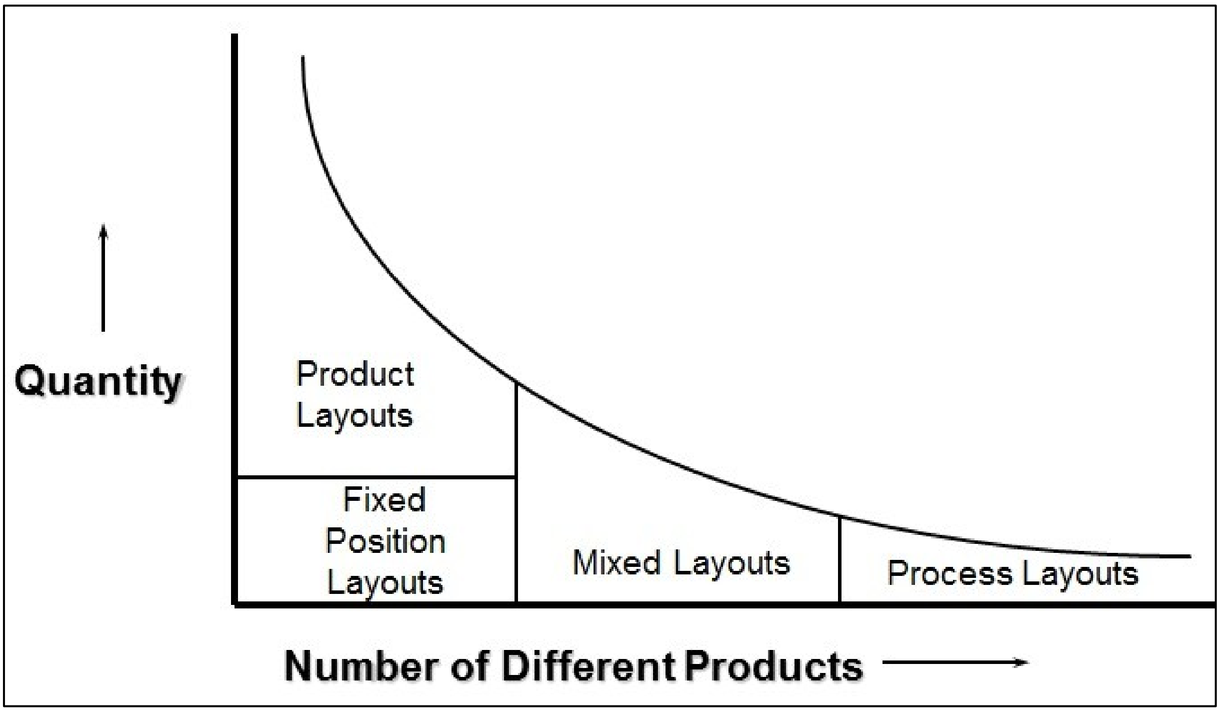


Fig.16 Graph showing the different types of layouts in regard to the product quantity and number of different products [12].

MFA defines the terms and procedures to achieve a material balance of the systems. Physically, a law known as the conservation of mass has been established and states that matter cannot disappear or be created spontaneously. The first step in MFA is to establish a mass balance of goods and selected substances. The definitions of goods and substances are the following: “Goods are defined as economic entities of matter with a positive or a negative economic value. Goods are made up of one or several substances. A substance is any element or compound composed of uniform units. All substances are characterized by a unique and identical constitution and are thus homogeneous”. Establishing the mass balances for goods and substances helps to detect the sources of error that could not be found using only one of them [13].

The objective is to keep a continuous material flow without any bottlenecks. Bottlenecks are the points of the supply chain with a limited capacity that slow down the whole production chain. They occur when the output on one machine is faster than the input on the following one, which results in the overstock [15].

For example, in this case the element of manual handling of the material can be classified as a good, because it has a direct impact on the economics of the company. Defining of the substances gives a more detailed look on the manual handling of the material, therefore divides it into separate operations such as unloading of the machine, loading of the boxes, dimension control and others. The MFA analysis for the manufacturing cell of the cams has been done in the past by an external company specialized in this domain. Therefore, this thesis will not deal directly with the MFA and will concentrate on analyzing of the machining, the transportation and other operations related to the first production cell.

To analyze these processes, it is necessary to know the exact order of the primary and secondary operations, both done by the machines and the human. Besides that, it is needed to know the time of the operations, their frequency and which operations are running in parallel with the others. A good way to make this analysis is to create a so-called Gantt chart.

Gantt chart is a type of a bar diagram named after H.L. Gantt, an American engineer who was a pioneer in its usage during the WW1. It is usually used for project management showing the relations between the time and the different operations. The operations are shown on the axis Y and the time, usually in days, is marked on the axis X. It was quite complicated to use it in the past, because the projects often change and it was necessary to remake the whole graph. It has become very popular with the arrival of the computers, which provide the much-needed flexibility and simple adjustment [14].

In this case, the diagram will be adjusted for the analysis of short-term operations lasting for several seconds or minutes and not days. Even though, the principle stays the same and it becomes a powerful and transparent tool for operation planning and organization. Thanks to its flexibility, even small modifications are easily considered and the changes are visible immediately. The most complex part of the analysis is the milling operation, because there are several sizes of cams machined during one shift and the sizes can be changed irregularly. This complicates the material flow and destroys its continuity because the lathe can machine only one size of the cams at a time. That means a buffer for each size of the cams should be needed between the lathe and the milling machines, to stock them and have them prepared for the milling.

2.3 Specifications on the working cycle

Currently, the fabrication cell is operating in two different shifts depending on the machine. The lathe, the milling machines and the heat treatment station are being operated in two consequential 12 hours long shifts 7 days a week, the grinders are being operated in three consequential 8 hours long shifts 5 days a week. After the automation, the working shifts on the grinders are to be elevated to be equal to the other machining centers, so the whole cell could run 24 hours 7 days a week, respecting the OEE of 90% and excluding the maintenance and setup time, and any unexpected stops.

2.4 Specifications on the machines and their operation

The position of the machining centers must secure the safety of the operator during the machine setup, change of tools or other necessary interference. Also, it must assure a good accessibility with a minimal slowdown of the fabrication process and the positioning must be optimal for the robot manipulation, to use it up to its full capacity.

The operation of the lathe should be semi-automatic, the operator should load the conveyor entering the machine and do the machine setup. The work pieces after turning should be dropped on another conveyor and brought to the marking machine automatically. It is important that the lathe production rate will be optimal for a defined number of milling centers, to avoid the idle time of these machines or contrariwise the excessive accumulation of the products on the conveyor.

The two milling centers must be positioned in the radius of the manipulation crane to enable a simple change of fixtures for different cam sizes. In case of a problem with one of the milling centers, the operator/technician must have access to this machine to solve the problem, without any danger from the robot. The two milling machines are identical, each of them has two reversible clamping jigs prepared in advance for different cam sizes. In the current process, the cams are being fixed on the fixture manually by the operator, using the clamps and the tightening screws. The operator uses a torque tightening drill to fix the parts with a precise tension. This operation would have been too complicated for the robot so it is necessary to work on a new solution, such as hydraulic clamping for example.

The heat treatment station is already semi-automatic with a minimal intervention of the operator and will not be highly affected by the automation. Although, it is possible to implement a conveyor transporting the full palettes from the milling centers directly to the station, which would decrease the operator's work. Every palette requires a protocol to be filled by the operator and this operation should be provided automatically. Therefore, the different machining centers should communicate in real time to ensure a fluent work flow and to adapt to the changes of the batches between different sizes of cams.

The currently used machines are manually operated vertical grinders with magnetic clamping. They could be replaced by one new semi-automatic grinder loading the products from a conveyor. This new machine shall increase the working time regime from the current situation to 24 working hours 7 days a week. This configuration will require less intervention of the operator and at the same time increase the productivity [3].

2.5 Equipment interaction and overview of the functions

To arrange the various interactions on the machining cell, a flowchart representing each domain of interaction was created. There exist some internal specifications of the company, considering all the possible interactions regarding their function and the criteria and the level of flexibility where 0 represents no possibility of changing of the requirement. In tab. 2. are specified the general requirements and restrictions for all types of operations within the first cam machining cell. This table represents the basic requirements that must be respected in any proposed configuration of automation.

Fig.17 Flowchart of interactions on the machining cell [27].

Tab.2.5.1 General requirements for any operations running within the cam machining cell [27].

	Main function	Criteria	Restriction	Flexibility
1.1	Initial pick-up of the part	Picking-up from the supplier box	Box size, part orientation	2
			Different suppliers	2
		Crash due to pick-up failure	None	0
		Pick-up failure (part rejected)	Less than 5000 ppm	1
		Operator assistance needed	Display the reason of failure	2
1.2	Loading of the lathe	Part orientation	Studs face down	0
		Conveyor setup	Different for each batch	0
		Work holding free of chips	0 chips allowed	0
1.3	Unloading of the lathe	Part free of chips	0 chips allowed	1
1.4	Loading of the stamping unit	Orientation	Studs face up	0
1.5	Unloading of the stamping unit	Unit damages	None	0
1.6	Loading of the measuring station	Part orientation	To be defined	2
1.7	Dropping of the part in the WIP	Capacity of the WIP area	6 pieces minimum	2
1.8	Loading of the milling machines	Machine sequence	First machine available	1
		Work holding is free of chips	0 chips allowed	0
		Part orientation	Studs face against the fixture	0
			Angular orientation	
1.9	Unloading of the milling machine	Part free of chips	0 chips allowed	1
2.0	Deburring of the part	Part free of burrs	No burrs/cutting edges	1

2.1	Loading of the measuring station	Part orientation	To be defined	2
2.2	Loading of the palette for the thermal treatment	Part orientation	Defined by the working process	1
		No physical contact between the groups of parts	Usage of the centering rings	2
2.3	Loading of the thermal treatment station	A completely loaded palette	0 uncompleted palettes	0
2.4	Unloading of the thermal treatment station	Good quality of the surface	Regular surface quality for all parts	0
2.5	Dropping of the parts in the WIP	Capacity of the WIP area	192 pieces minimally	2
2.6	Loading of the grinder	Part orientation	Studs face down	0
		Conveyor setup	Different for each batch	0
		Work holding free of chips	0 chips allowed	0
2.7	Unloading of the grinder	Part is free of chips	0 chips allowed	0
2.8	Loading of the measuring station	Part orientation	To be defined	2
2.9	Dropping of the parts in the WIP	Capacity of the WIP area	96 pieces minimally	2
3.0	Ensuring of a safe loading of the parts	Scrap rate due to miss load (chips, improper positioning)	Maximal allowable scrap rate is 500 ppm	1

2.6 Identification of existing automation elements

The automation of production is currently a big project within the PH group, and many plants in the world are working on it. After starting in the USA, the European branches are joining the project. Nowadays there exist lots of possibilities and lots of different companies dealing with robotization and automation of the fabrication processes. In general, they offer the same type of products for similar applications in the industry, however there are a few of them with the best references and the technical solutions that separate them from the others. To maintain the objectivity of choice it is necessary to consider several solutions and compare the propositions of different companies.

2.6.1 Products, solutions and services

It has been chosen to contact at least four producers of robots to obtain four different propositions. The companies that were contacted are – FANUC, ABB, KUKA and YASKAWA. A separate meeting in the PH factory was organized with the sales representative of each company. During these meetings, basic information were exchanged between PH and the robot producers, such as information about technical possibilities of the robot suppliers and the technical needs of PH. Every company has a different marketing and sale strategies, some of them provide everything from the software, through the mechanical elements up to the robots, the others work with integrators. The integrators are companies associated with the robot producers that provide the rest of the automation equipment.

2.6.1.1 FANUC

FANUC is originally a Japanese robot producer founded in 1958, nowadays one of the world leaders in robotization and automation operating on all continents. With more than 100 robot models, it has the widest portfolio in the world covering nearly all industrial applications. Besides the robots, FANUC is well known for the production of the numerical control systems and servo-units that are currently covering 65% of the global market. Moreover, the company has an own mark of machining centers for highspeed milling, injection molding and wire electro-discharge cutting called ROBODRILL, ROBOSHOT and ROBOCUT [16].

FANUC is offering the robots from the smallest application with 1kg payload up to the biggest robot produced in series with the payload of 2,3 tons, used for manipulation with vehicles for example. In addition, there exists a special type of robot called the collaborative robot designated for the collaboration with the operator without needing a protective fence [17].

The corporation offers many high-tech functions and equipment such as 2D or 3D visual detection, control of vibration, force sensors used for measurement and control, real-time communication between the robots that allows less idle time and a so called Dual Check Safety (DCS). Using the position sensors, the robot does not leave the predefined area that can be displayed by the operator on the control unit. This allows reducing the needed space, thanks to eliminating the need of a protection fence. In case of entry of the operator into the area, the robot automatically stops the movement until it is safe to continue [17].

2.6.1.2 ABB

ABB is a Swedish-Swiss multinational company created by merging two companies in 1988. It is the largest producer of electricity grids in the world and is active in many sectors such as electrification products, robotics and motion, industrial automation and power grids [18].

ABB is one of the leading robotics suppliers in the world operating in 53 countries. The key industrial markets for the company are foundry, automotive, aerospace, solar industry, food and beverage and plastics. The company has numerous experiences in delicate applications such as machine tending, deburring, palletizing, grinding, spot welding and many more. It is also well known for its collaborative robot called YuMi with a precise visual system, force regulation and other safety functions and the ability to learn how to work instead of only follow the program [18].

Recently they have integrated a company specialized in material tending, which gives the company the advantage from the concurrence. The feature so called SafeMove 2 is trying to fill the needs for an opened automation environment, without the safety fences. By using a “light gate” it allows robots and operators to work more closely together. The robot has a restricted area of movement used for a specific application and thanks to the integrated movement detectors, after a person steps inside a designated area, the movement speed of the robot is either slowed down or stopped depending on the needs [19].

2.6.1.3 KUKA

KUKA is a German company founded in 1898 which was fabricating street lighting and welding machines. In the year 1973, the company has built its first robot known under the name FAMULUS. It was the first industrial robot in the world with 6 electromechanically actuated axes [20].

KUKA is one of the world leaders in robotization as well, offering all the robot peripheries such as linear movement units or different effectors. The offer of the robots is wide starting with the small light construction robots, through bigger robots meeting the highest hygienic criteria for working in the food industry, up to the biggest robots resistant to high temperatures and aggressive environment [21].

The company is also known for manufacturing different manipulators and positioners. These are often of big dimensions and adapted exactly to the customer’s needs. KUKA so called omniMOVE is a mobile platform usually used in aeronautics and space industry, for manipulating with heavy parts with an extreme precision.

KUKA has a lot of experiences in automated welding and is also offering the welding machines, installed in more than 44 countries which is putting the company into the top world leaders in friction welding [22].

2.6.1.4 YASKAWA

YASKAWA is company created in 1915 in Japan and is specialized in production of inverters (1.6 million per year), servo-units (800 000 per year) and robots (22 000 per year). The main headquarters for the European market is in Germany and the factories are located also in Germany, Sweden and Slovenia [23].

The company offers a vast variety of robots as the other companies mentioned bellow with comparable technical properties. The main advantage of the company is, that it is producing the main parts for the drive and motion of the robots such as inverters, servo-units, machine controllers but also a lot of electronic devices like so called I/O systems, control systems, teleservices and HMIs [24].

Robot supplier	FANUC	ABB	KUKA	YASKAWA
N°of installed robots worldwide	400 000+	300 000+	80 000+	300 000+
Types of robots	Articulated, collaborative, delta, palletising, arc welding, top mount, paint	Articulated, collaborative, delta, palletising, arc welding, top mount, paint, door opening	Articulated, collaborative, palletising, arc welding, top mount, paint, foundry	Articulated,press break tending, palletising, arc welding, top mount, paint, foundry
Weight range	up to 2,3 tons	up to 800 kg	up to 1300 kg	up to 800 kg
Radius range	up to 4683 mm	up to 4200 mm	up to 3901 mm	up to 3500 mm
Precision of repeatability	±0.02-0.5 mm	±0.02-0.15	±0.05-0.15	±0.015-0.5
Technical advantages	2D and 3D part recognition, motion functions, Double Check System	2D and 3D part recognition, positioners, SafeMove system,atomiser,	2D and 3D part recognition, central cloud data storage, omniMOVE	2D and 3D part recognition, Mobile Robot Platform
Integrators	YES	NO	YES	YES
Service	Standard Services, Special Breakdown Support, 25 Years Guarantee for Spare Parts	Standard Services, Distant Monitoring, Data Backup, Spare Parts Packages	Standard Services, 10 Years Guarantee for Spare Parts,	Standard Services, Backup Units, Distant Monitoring
Other fabricated products	Machining centers, control units, servo-units	Packaging stations, pressing systems, various material handling stations	Manipulators, positionners, welding centers, foundry machines	inverters, servo-units,
Sources	[16], [17]	[18], [19]	[20], [21], [22]	[23], [24]

Fig.18 Shows a table with basic information about the four considered robot producers that could influence the final choice. It is important to note, that the value of the precision is true only for a specific trajectory and must be discussed with the competent employees.

3 PROPOSITIONS OF AN AUTOMATED FABRICATION CELL

This part of the thesis introduces the possible solutions with regards to all the details and processes. With respect to the analyzed data and to different restrictions, several propositions are discussed. These can be classified in two main categories – implementation of automation using the current machines and implementation of automation and new machining centers. Propositions from other PH plants are also considered, compared with the needs of the plant in Brno and modified to fit the constraints. All the propositions will concentrate on automation of the turning and milling processes. The heat treatment station is already automated and does not require any changes.

3.1 Using of the current machining centers

3.1.1 Configuration #1

This is the easiest proposition, because it is simplified and omits certain operations that are currently part of the fabrication process. It was used only as the first step in finding the best proposition. One robot IRB 4600 with technical specifications in the Annex 1, is used for manipulation with the work pieces and machine tending, using the current machining centers – one lathe and two milling centers. Both milling machines and the conveyor must be in the radius of the robot. The original conveyor must be modified to provide enough space to stock the cams and must transport them into the radius of the robot.

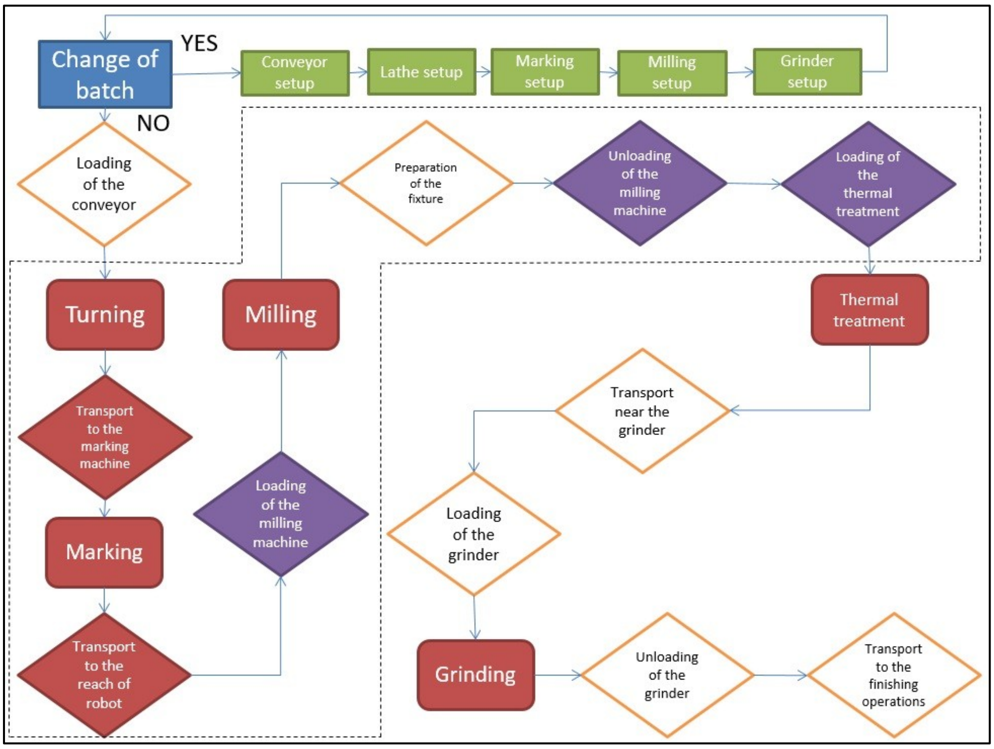


Fig.19 Workflow of the first proposition, the dashed line separates the fabrication cell in two parts – the first considered to be automated, the second to stay the same. The rectangles represent the preparation operations, rounded rectangles represent the value-added operations and the diamonds represent the non-value-added operations. In red are the different machine operations, in purple are the operations done by robot and in orange by operator.

The operator brings the palette with the raw material using a palette truck to a defined place. After that he manually loads the conveyor of the lathe with 10 work-pieces, these are automatically loaded into the machine. The machined parts are dropped on a second conveyor, on which the marking machine is placed. Every part is marked with a data matrix using a laser marker.

The robot is equipped with a double gripper adapted to manipulate with different size of cams. After the marking operation is finished it will pick up a turned work piece from the conveyor with one side of the gripper, unload one milled work piece with the second part of the gripper, load the milling machine and put the milled work piece onto the palette. The gripper is also adapted to manipulate with the centering fixtures that are put between each 2 pieces of the milled work-pieces, and with a centering bar so the robot is capable to assemble the palette for the thermal treatment.

This solution does not count with a buffer, it provides a continual material flow, the production plan will have to be adjusted for the new automated cell. Instead of milling several sizes of cams during the shift, there will be only one size produced at a time. During the change of batch, all the machines will be set up for another size of cams.

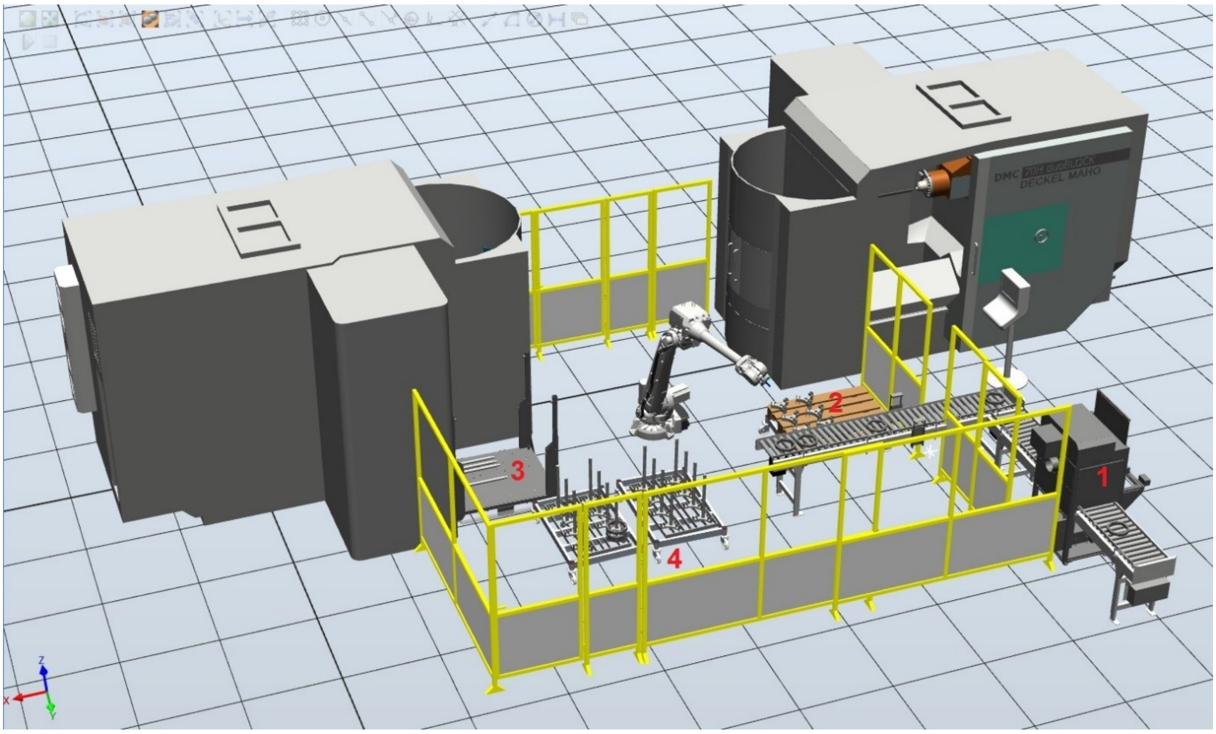


Fig.20 3D model of the configuration #1 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; number 1 refers to the marking machine, number 2 to the palette with the centering fixtures, number 3 to the palette with the centering bars and number 4 are the palettes for the thermal treatment; more images of this configuration can be found in annex 2.

The main improvements when comparing to the current situation are the reduction of the operator's responsibilities, which leads to better working conditions for the operators and financial savings discussed in chapter 4.1, as less operators are needed for the cell operation. In this simplified version, the robot is used only to 1/4 of its capacity as can be seen on figure 21.

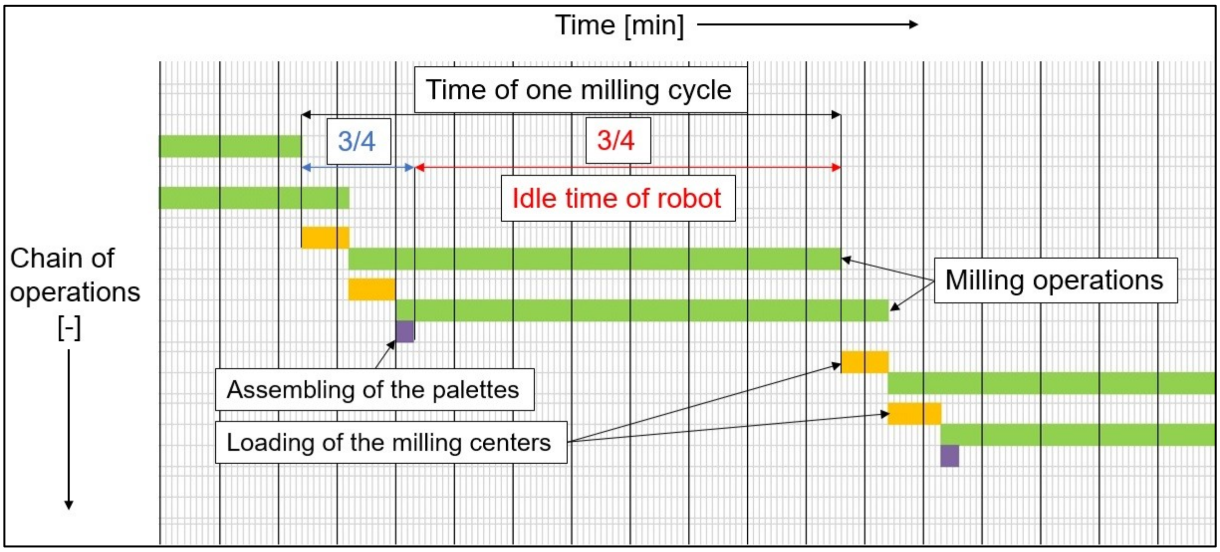


Fig.21 A part of a Gantt chart showing that the minimum idle time of the robot would be ¾ of one milling cycle. The cycle is composed of loading of the two milling centers, milling and assembling of the palette. The assembling is only done after a palette is fully loaded and ready for the next operation. One palette has the capacity of 96 cams.

The main problem of this solution would be the low usage of the robot. This could be improved by taking into consideration the omitted operations of the process, such as dimension checking and cleaning of the cams from the burrs. This would extend the time of the manipulation and shorten the idle time of the robot. However, the aims of this proposition were to identify the hidden complications. After analyzing the Gantt chart of the turning and milling operations, it was discovered that the takt time of these two operations is not synchronized. Takt time is the time measured from the start of production of one unit until the start of production of the next unit [25].

This leads to the creation of a bottleneck between these two operations. The production speed of the lathe is bigger than the loading speed of the milling centers, because the milling operation is longer than the turning operation. After one complete machining cycle on each of the two milling centers there are 3 cams accumulated on the conveyor. For an 8 hours long work-shift, it is approximately 88 accumulated cams. This proposition proves the need of using a stock buffer between the turning and milling operations even after the adaptation of the production plan. Other problems of this configuration are the missing control station, production of only one size of the cams at a time and the intervention of an operator for transportation of the full pallets to the thermal treatment station and their replacement with empty palettes.

3.1.2 Configuration #2

The second proposed solution is the last from the first category – implementation of automation using current machines. Basis of the solution come from the first proposed configuration and it tries to improve its disadvantages, for example low usage of the robot and lack of automation of the secondary operations. To cover all the necessary operations, two robots IRB 4600 with technical specifications in annex 1, instead of one should be used as can be seen on figure 23. First robot will be operating the operations between turning and milling and the second will be operating the milling machines and load a conveyor after the thermal treatment.

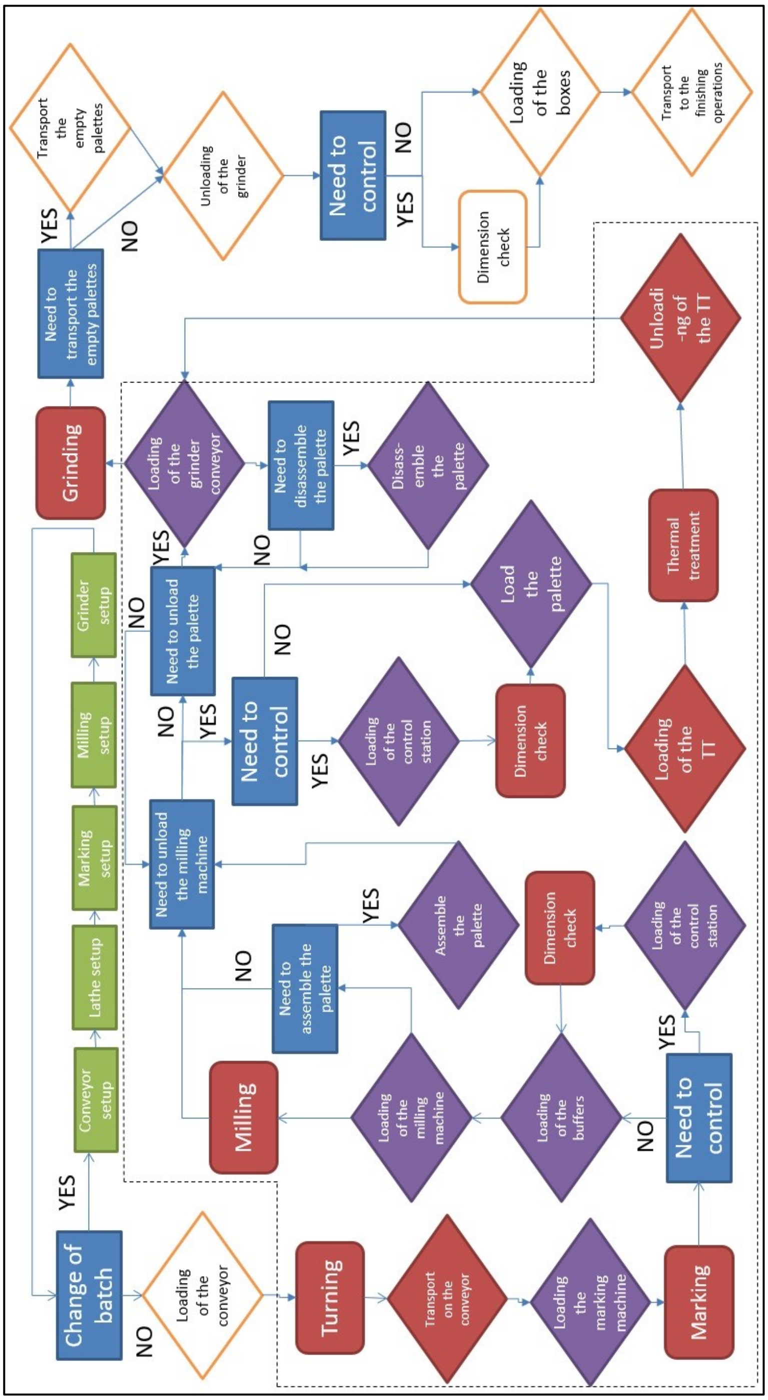


Fig.22 Workflow of the second proposition, used symbols are similar to those used in the workflow of the first proposition.

The beginning of the fabrication process is similar to the configuration #1. The loading of the conveyor is again provided by the operator and in the same frequency, the turning is semi-automatic and the first difference comes at the end of the turning operation. The cams are loaded by the first robot onto the marking machine, which is independent from the conveyor. After the marking, the work-piece is loaded into the buffer in the radius of the second robot. Thanks to the usage of the robot for the manipulation after the turning operation, the frequency of dimension checking can be increased, which leads to a better customer satisfaction. Instead of checking every 7. work-piece, every other can be checked.

To avoid the creation of a bottleneck between the turning and milling operations, a buffer is placed in the radius of both robots. This buffer has a maximum capacity of 96 pieces of cams. The capacity of the buffer is calculated to cover the accumulated cams for one 8 hours long work-shift. The operator must intervene to carry it away and replace it with an empty one. The change of the buffer is a quick operation during which all the operations provided by the robot operating the milling centers must be paused. This is assured by using the light gate defined in chapter 2.6.1. There is a secondary buffer placed in the radius of both robots, so the first robot can continue working in case of some unexpected errors associated with the second robot.

The second robot picks up the work-piece from the buffer and loads the milling centers, executing the same operations as described in chapter 3.1. besides the manipulation with the centering bars. In this configuration, the robot is not static but placed on a rail allowing it to be more flexible and operate during the milling of the work-pieces. It is a special track motion platform designed as a 1 meter long module. These modules can be assembled until the total length of 21 meters, maintaining the position repeatability of ±0.05 mm. The maximum payload for the platform is 1200 kg, with a maximal travel speed of 2 m/s [26]. The platform is 8 meters long so the robot will be able to operate the two milling centers and to unload the cams from the palette after the thermal treatment onto a conveyor leading to the grinding machines. This unloading operation is done in parallel with the milling of the cams, so the idle time of the robot is significantly reduced.

This configuration is optimized for several working conditions:

- production of only one size of the cams,
- the palettes for thermal treatment are prepared by the operator,
- full palettes are automatically loaded and unloaded from the thermal treatment station,
- the grinding operation is ±8 minutes long,
- the capacity of the conveyor for the grinding machines has the capacity of 16 work-pieces.

In case of any changes of these predefined conditions, the whole concept must be adapted to the specific situation.

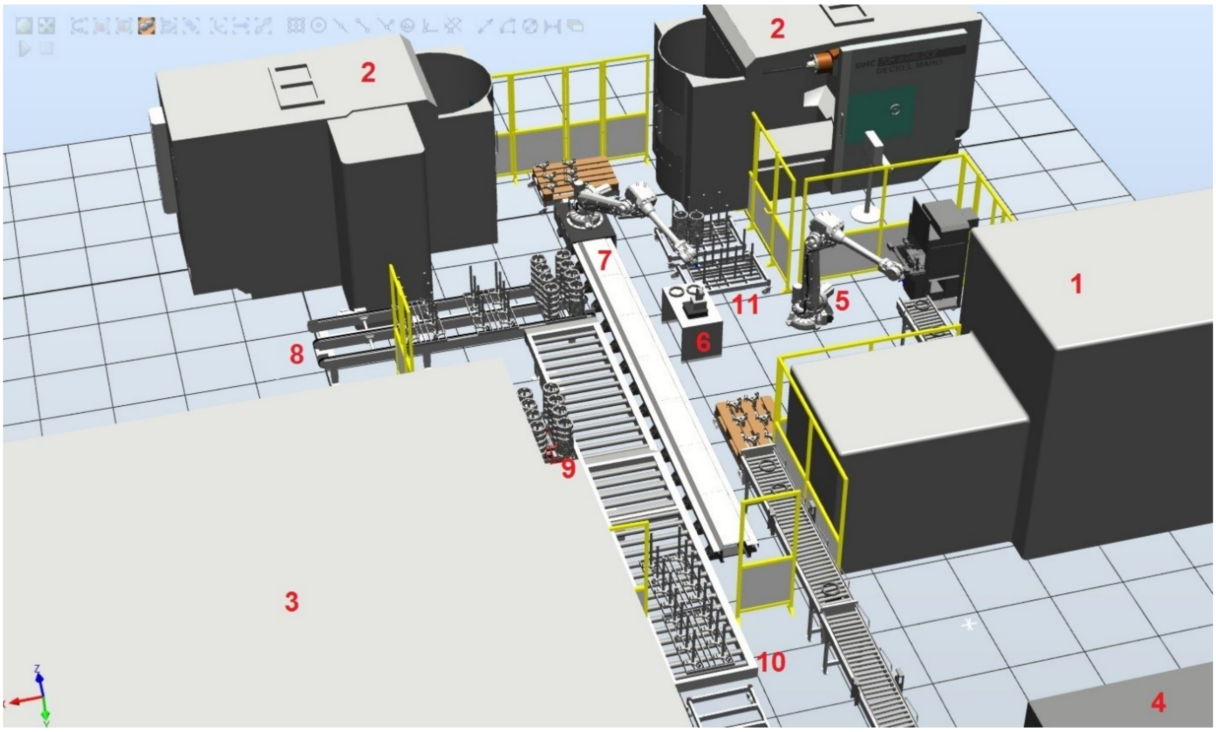


Fig.23 3D model of the configuration #2 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 3.

In the fig.23 the references are the following:

- 1 – vertical lathe,
- 2 – milling centers,
- 3 – thermal treatment station,
- 4 – grinding machine,
- 5 – static robot,
- 6 – control station,
- 7 – robot on a rail,
- 8 – entry of the empty palettes,
- 9 – lift for the full palettes from the conveyor to the thermal treatment station,
- 10 – exit of the empty palettes,
- 11 – buffers for the turned work-pieces.

The models of the machines do not correspond exactly to the machines that are currently being used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine and of the milling centers are from the source [27].

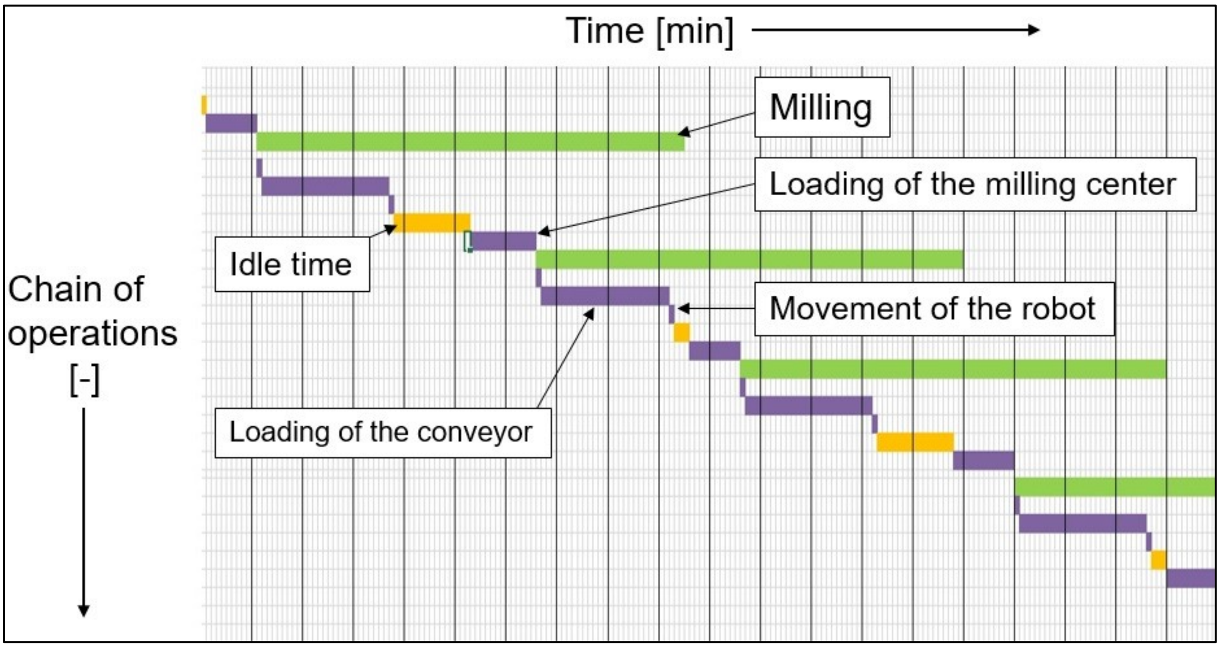


Fig.24 A part of a Gantt chart of the processes of the second configuration. In green is marked the milling operation, in purple the operations of the robot and in yellow the idle time of the robot.

As shown on fig. 24, the idle time of the robot operating the milling centers has been reduced to only 1/3 of the cycle time thanks to the use of a motion rail. This is a significant improvement comparing to three quarters of the cycle time in configuration #1. Also, the process is more automated and requires less intervention from the operators, reducing the time of investment return by reducing the number of needed operators for the fabrication cell.

This configuration is proposed as a solution for several problems of the configuration #1. Firstly, this solution includes the dimension checking operations after each of the machining processes. Secondly, the operator no longer needs to transport the heavy palettes to the thermal treatment station, as this is provided by the conveyors. Also, the idle time of the second robot is decreased, however the usage of the motion rail occupies a lot of space causing the impossibility of production of different cam sizes at the same time.

In this current configuration, the first robot has a maxim idle time of only 1 minute, thanks to the increased dimension controlling frequency. There is a possibility to modify the lathe, so that to conveyor for entering of the raw parts would be positioned in the radius of the first robot. This would enable the automation of loading of the lathe, however an additional system for 3D visual detection must be installed which will increase the amount of the investment. This option is marked as configuration #2b and the economic impact and comparison with other options is discussed in chapter 4.4 and 5.

3.2 Implementation of new machining centers

In the present days, the customer demands are more and more challenging for the producers. High precision, high reliability and shorter lead time are the most important factors. The producer should answer all the customers' needs and the precision of the machines is one of the keys to it. There exist several sources of precision errors, for example the vibrations of the machine, inaccuracy of the spindle positioning, static deformations of the group spindle-bearing or the errors of the commanding. Due to the constant mechanical stresses acting during each machining operation, the machines lose the precision even more with aging [29].

Especially in the case of automation, the age of the machines can be problematic. Often, they do not have any advance preparation for upgrading and implementation of automation elements, such as hydraulic clamping, automated door opening or software communication with the robots. This implies elevated additional investment in the machine park discussed more in chapter 4, so it is eligible to consider modernizing of the machine park. Not only the implementation of the automation elements would be less expensive, but also the production precision would be increased and the maintenance time will be reduced in general.

3.2.1 Considered new turning centers

3.2.1.1 Doosan Puma V8300

Doosan is originally a Korean conglomerate company active in several different engineering sectors, infrastructure support, consumer and service business and many more. The division Doosan Machine Tools has been founded in 1976 and started the production of machine tools and it was in 1980 when the first NC lathes was developed. Today this division belongs to the group of the biggest producers of machining center in the world [30].

The model Puma V8300 is a standard vertical turning center with a maximal turned diameter of 830 mm, maximal turned length of 750 mm and the maximal spindle speed of 2000 rpm, which fits the needs to produce the SE cams [31]. The advantages are that machines are currently on stock and available to be delivered in 3 months. The disadvantages are that the power supply must by modified and that the loading cycle time would be longer comparing to the current situation. More technical data are available in the Annex 4.

3.2.1.2 Famar Tandem 415

Famar is an Italian company founded in 1973 that started the production of special machine tools for the automotive industry. In the year 1986 the company entered the market of production machines with its own twin-spindle horizontal lathe. Afterwards, the company has expanded and opened new plants across Europe. Currently it tries to satisfy the growing demand for automation elements and proposes innovative machine solutions and equipment [32].

Tandem 415 is a two-spindle vertical lathe with a so-called Power spindle for heavy machining jobs. The basic equipment of the machine includes automatic loading and unloading of workpieces by a pick-up spindle. The maximal turning diameter is 400 mm and the maximal turning length is 300 mm with a maximal spindle turning speed of 4000 rpm. More technical data are available in the Annex 5.

3.2.1.3 DMG MORI NLX 3000 (700) and NZX 2000

DMG MORI is a company created by a collaboration between the Japanese Mori Seiki C., Ltd. and the German Gildmeister AG manufacturers of machine tools in 2009. The company concentrates on production of complex production machines such as parallel-twin-spindle turning centers, multi-axis turning centers, vertical and horizontal machining centers but also on operating systems and other machine equipment [34].

The NLX 3000 is high-rigidity horizontal turning center for precise operations, equipped with a thermal displacement control. The maximal spindle speed of the model is 3000 rpm and the work-pieces can be machined up to the diameter of 430 mm and the maximum turning length of 713 mm. More technical data are available in the Annex 6 [35].

The NZX 2000 is also a horizontal turning center but with 2 spindles and 2 turrets that can work independently. The maximal spindle speed of the machine is 5000 rpm, the maximal turned diameter is 320 mm. Depending on the options, the maximal travel in each axis can vary. More technical data are available in the Annex 7 [36].

3.2.2 Considered new milling centers

3.2.2.1 DMG MORI NHX 5000

This model is a general-purpose horizontal two-block machining center with a short distance between the spindle end face and the center of the palette, which enables using of short tools. The maximal rotation speed of the main spindle is 15000 rpm and the maximal palette working surface is 500x500 mm. More technical data are available in the Annex 8 [37].

3.2.2.2 DMG MORI NT 4250

This machine is a multi-axis mill turn center offering a complete machining, with the milling spindle maximal speed of 12000 rpm and the counter spindle maximal speed of 6000 rpm. It is a full-valued replacement of one milling and one turning center with the ability to create even more complex shapes in one working cycle, using one clamping position. More technical data are available in the Annex 9 [38].

3.2.3 Configuration #3

In this solution, the currently used vertical lathe is replaced by two new horizontal turning machines NLX 3000 described in chapter 3.2.1.3. The milling centers could be also replaced by the NHX 5000 described in chapter 3.2.2.1. The choice to keep the current milling centers or to replace them with new ones can be made based on the investment analysis in chapter 4.5. Two robots IRB 4600 are used, the technical details can be found in Annex 1. The first one for operating the turning centers and second one for operating the milling centers.

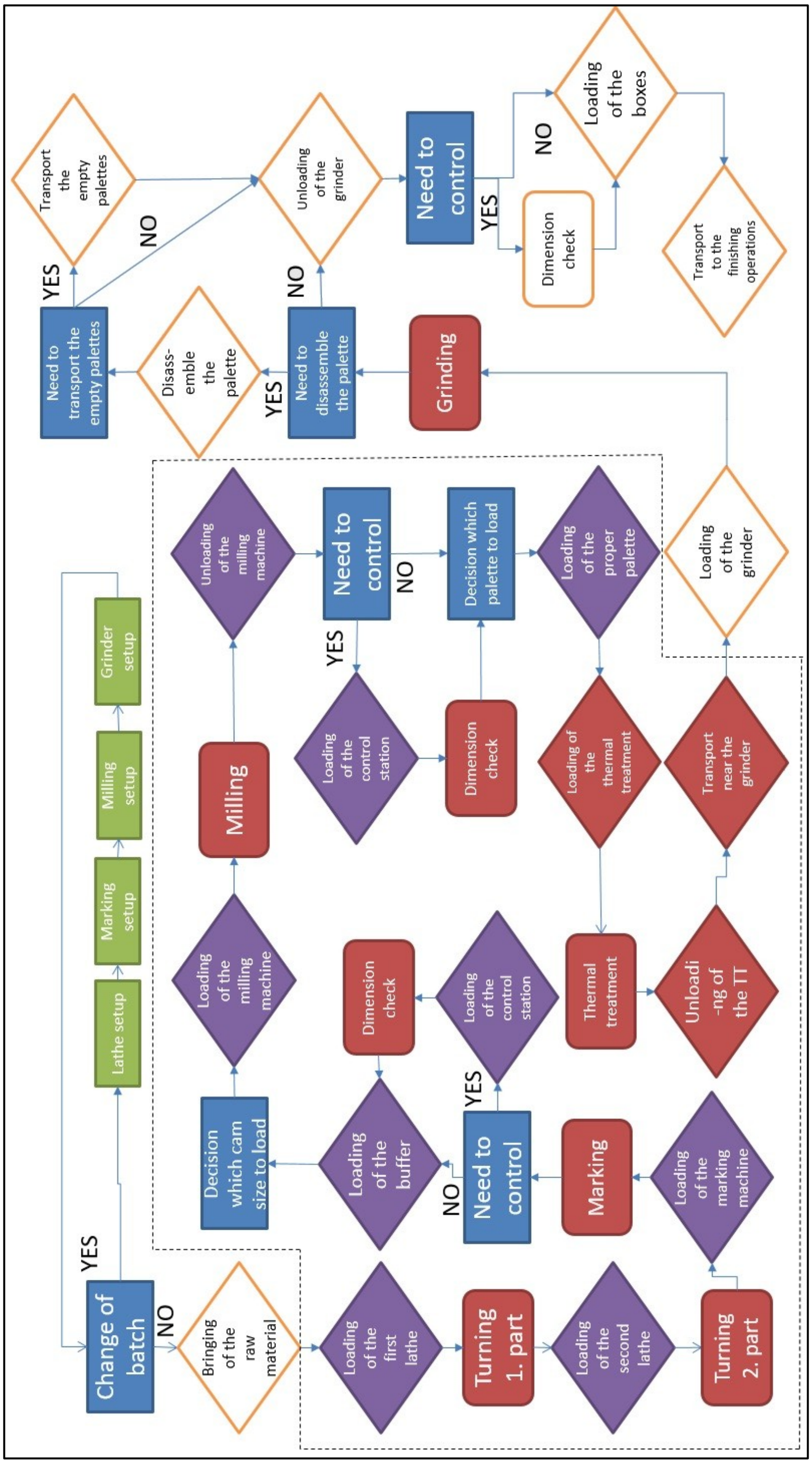


Fig.25 Workflow of the third proposition used symbols are similar to those in the figures 19. and 22.

Loading of the turning centers is no longer done by the operator, he only brings the palette with the raw work-pieces to a designated place from which the robot loads them. This innovation decreases the operators´ occupation and creates the time for other work activities. The first robot loads the first lathe where the first side of the cam is machined, then it is loaded to the second lathe for the second part of the turning operation. Afterwards, the cams are loaded onto the marking station by the robot and the marking is similar to the previous configurations.

To avoid the creation of a bottleneck between the turning and milling operations a buffer is used again. In this configuration, the buffer must have the capacity of 120 cams to cover the accumulation of turned parts during one 8 hours long working shift. The operator must intervene at the end or beginning of the shift, and replace the buffer with an empty one. Moreover, a second buffer is needed for the cams of a different size. This buffer is manually placed next to the first one. The capacity of the buffer is calculated for each size of the cams to secure that at the end of the shift, all cams from the buffer are machined and the operator can replace the empty buffer with another batch of work-pieces.

Before the beginning of every shift each of the two milling centers is prepared for machining of a different cam size. In this configuration, one milling center is machining the A cams that are being machined on the turning center in parallel and the second milling center is machining the C cams. The robot picks up the work-piece from a buffer and loads the designated milling center. Then it loads the second machine with the second size of the cams, picked up from the second buffer. After the milling is finished, the machined work-pieces are loaded on a palette for the thermal treatment. The palettes are brought to the robot by a conveyor and they vary for different cam sizes. However, after considering the dimension of each cam size it is possible to have similar palettes and centering fixtures for the cams of the sizes A/B and C/D. The palettes come to the radius of the robot with the centering bars already in their places so the robot needs to manipulate only with the cams and the centering fixtures. When the palettes are full, they are transported to the thermal treatment station and afterwards near the grinding centers where they are being unloaded manually by the operator. After they are unloaded, the operator must transport them to a designated place from where they are being loaded on the conveyor and re-used.

This configuration is optimized for several working conditions:

- production of cams of the sizes A and C in parallel,
- there is only one size of the cams machined on each machine,
- the palettes with the raw work-pieces are changed and the end of shift,
- the palettes for thermal treatment are prepared by the operator,
- full palettes are automatically loaded and unloaded from the thermal treatment station.

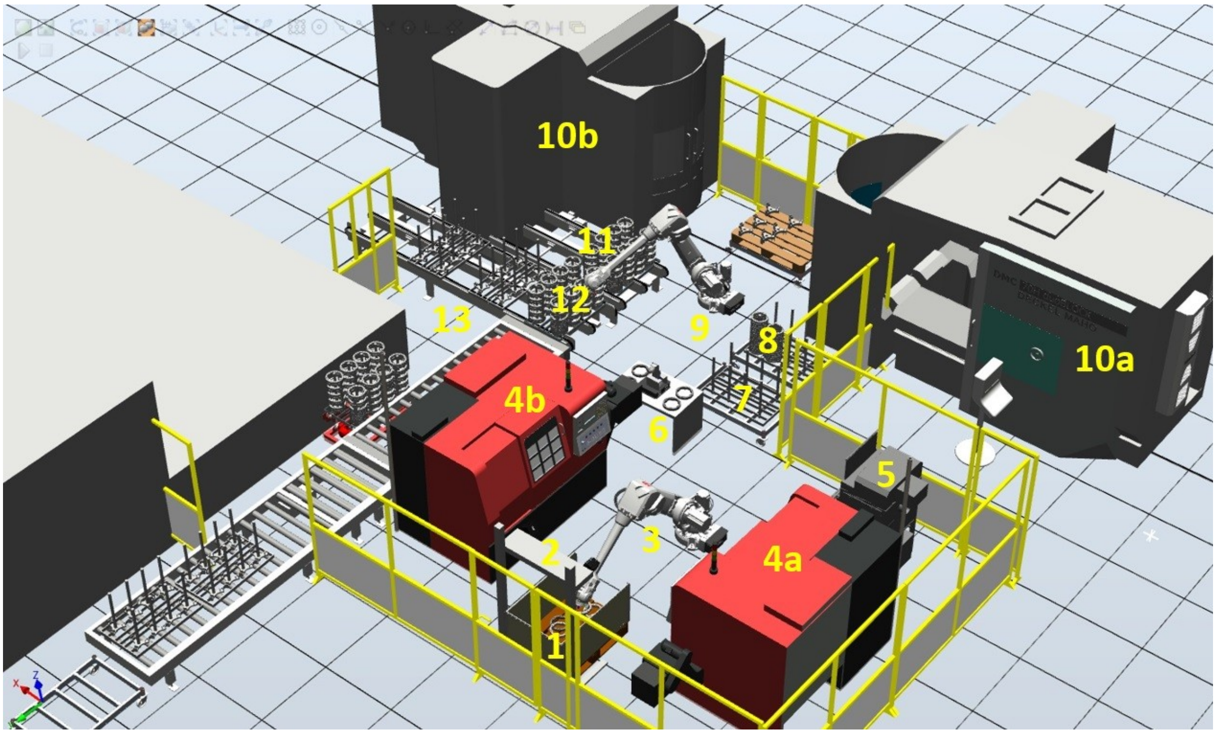


Fig.26 3D model of the configuration #3 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 10.

In the fig.25 the references are the following:

- 1 – palette with the raw work-pieces,
- 2 – 3D camera vision for automated picking of the raw work-pieces,
- 3 – first robot operating the turning centers,
- 4 – turning centers DMG MORI NLX 3000,
- 5 – marking machine,
- 6 – control station,
- 7 – buffer for the currently turned size of cams,
- 8 – buffer for a second size of cams,
- 9 – second robot operating the milling centers,
- 10 – milling centers,
- 11 – palette for one size of cams,
- 12 – palette for the second size of cams,
- 13 – automated conveyors transporting the palettes.

The models of the machines used in the model do not correspond exactly to the machines that will be used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine, turning centers and the milling centers are from the source [27].

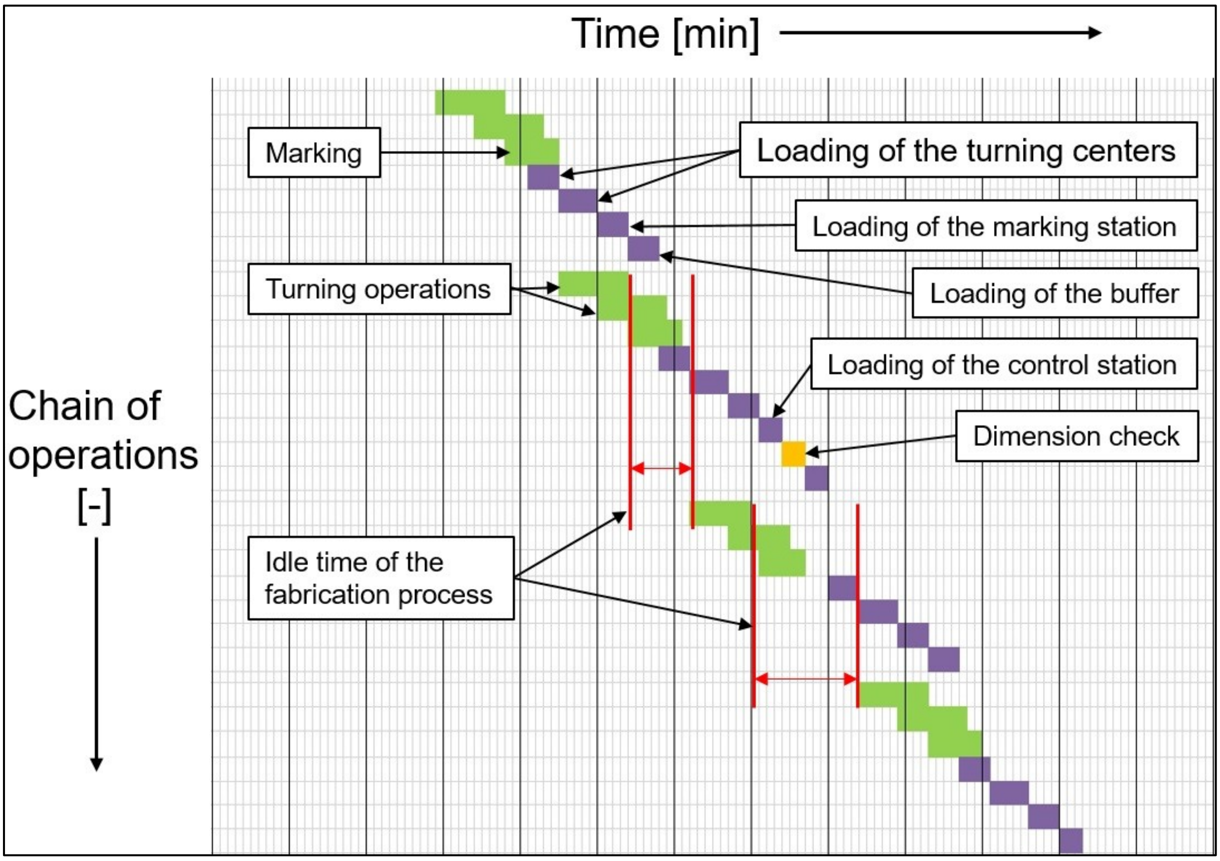


Fig.26 A part of a Gantt chart of the turning operations of the third configuration. In green are marked the machine operations, in purple the operations of the robot and in yellow the time of dimension controlling.

Fig. 26 shows the turning operations divided into each step, from loading of the raw work-pieces to loading of the buffer for the next operation. The two turning centers are operated in parallel by one robot, which is fully occupied. The biggest disadvantage of this configuration is that the turning process is constantly slowed down because of the robot. The slow-down time is marked with red lines on fig.26 and it marks the time between the end of a machining operation and start of a new one. The idle time of the turning centers gets bigger with the need for dimension controlling.

Compared to the configuration #2, there is no room for additional dimension checking after the turning operations in order to improve the quality of dimension controlling. In opposite to that, the second robot has a long idle time, similarly to the configuration #1 because it only operates the two milling centers. The time of turning is increased and the accumulation of the turned parts is decreased so there is no need for a second buffer. However, this proposition counts with production of two different cam sizes in parallel which causes the accumulation of the currently turned work-pieces. Due to this, the conveyor bringing the empty palettes to the radius of the second robot must be modified and is more expensive. The production plan in this configuration is much more complicated than in the first two propositions, because an automated cell is not flexible enough to solve the unexpected situations, such as incomplete loading of palettes for thermal treatment. The economic impact and comparison with other options is discussed in chapter 4.6 and 5.

3.2.4 Configuration #4

In this solution, the currently used vertical lathe is replaced by one new horizontal turning machine NZX 2000 described in chapter 3.2.1.3. The milling centers could be also replaced by the NHX 5000 described in chapter 3.2.2.1. The choice to keep the current milling centers or to replace them with new ones can be made based on the investment analysis in chapter 4.6. Two robots IRB 4600 are used, the technical details can be found in Annex 1. The first one for operating the turning center and second one for operating the milling centers, similarly to the configuration #3.

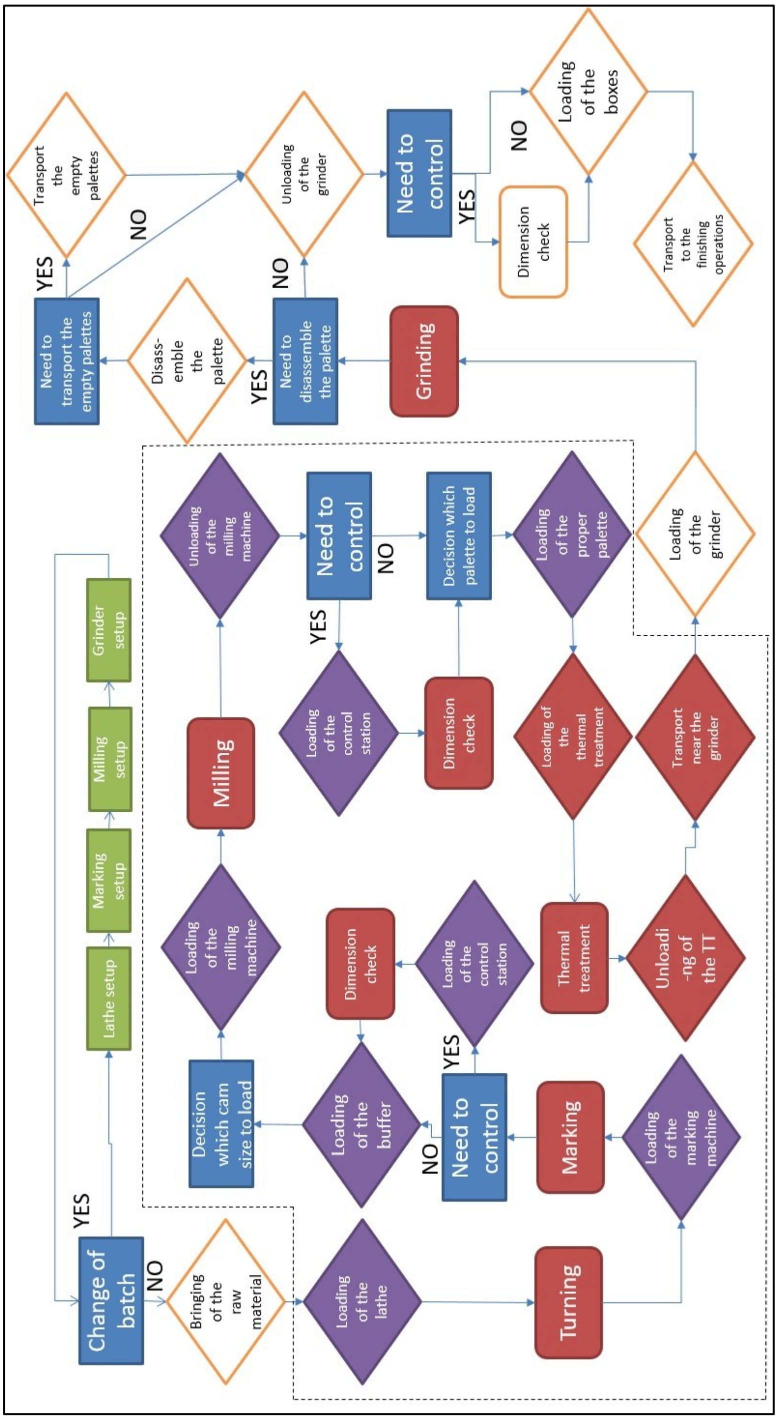


Fig.27 Workflow of the fourth proposition, used symbols are similar to those in the fig. 25.

In this configuration, only one turning machine is used. It is a CNC lathe with 2 spindles and 2 turrets that can work independently, so both sides of the cam are machined by one loading. The advantages are less space consumption and decreased time of manipulation compared with configuration #3. Loading of the machine is done similarly to the previous configuration. The operator brings the palette to a designated place and there is a 3D vision system placed over the palette composed of 2 separate cameras. These regularly scan the placement of the raw work-pieces. Thanks to this, the robot knows the exact position of each cam and is able to load them automatically into the turning center. The rest of the operations related to turning are the same as in the configuration #3. However, the extra space can be used to implement a rail for the second robot, or to install an external controlling station as shown on fig. 28, that would be operated by the operator.

The operator has the access to the basic controlling station and can intervene in the measuring process. He can take the cam out from the first station and bring it to the second one. The second station could be used to control additional characteristics that must be controlled on one piece from each batch. This problem has not been discussed yet in the configurations bellow, but will have to be treated. For the moment, the solution to this in the previous configurations is to install a measuring station near the thermal treatment station. After a full palette is loaded into the thermal treatment station by the lift, it does not enter the station directly. It is transported on an already existing conveyor and added to the queue, so the operator has the time to unload one cam of the batch safely and to control the additional dimensions. This is not very practical, but the optimal solution of this problem is needed to discuss in detail with the group control methods expert.

The buffers are similar to those in configuration #3, except that the number of the accumulated turned parts for an 8 hours long shift changes from 120 to 100. The time of manipulation is decreased, however the production rate of the turning center is lower than in the previous configuration. The configuration #3 allowed to turn two work-pieces in parallel, which is not possible when using only one turning center. The rest of the fabrication process is similar to the configuration #3 and discussed in chapter 3.2.3., as well as the conditions for which this configuration is optimized. The placement of different machines is changed and adapted to use the available workspace optimally.

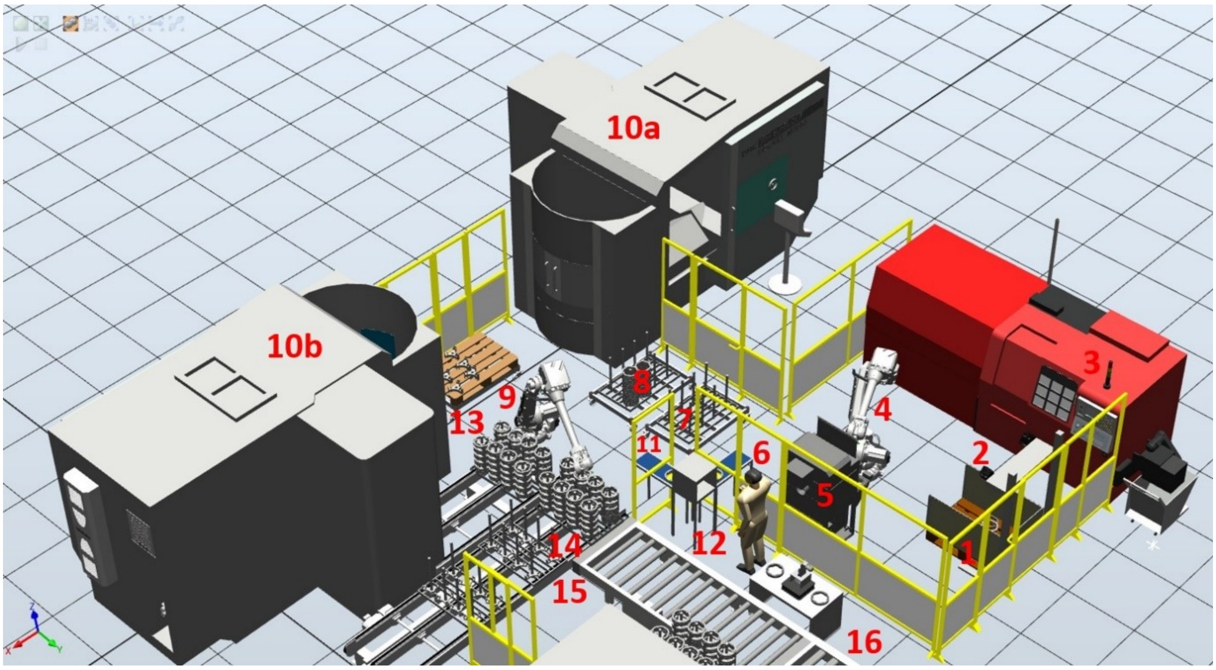


Fig.28 3D model of the configuration #4 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 11.

In the fig.28 the references are the following:

- 1 – palette with the raw work-pieces,
- 2 – 3D camera vision for automated picking of the raw work-pieces,
- 3 – turning center DMG MORI NZX 2000,
- 4 – first robot operating the turning center,
- 5 – marking machine,
- 6 – conveyor bringing the cams to the control station after the turning operation,
- 7 – buffer for the currently turned size of cams,
- 8 – buffer for a second size of cams,
- 9 – second robot operating the milling centers,
- 10 – milling centers,
- 11 – conveyor bringing the cams to the control station after the milling operation,
- 12 – control station for basic characteristics controlling,
- 13 – palette for one size of cams,
- 14 – palette for the second size of cams,
- 15 – automated conveyors transporting the palettes,
- 16 – control station for special characteristics controlling.

The models of the machines used in the model do not correspond exactly to the machines that will be used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine, turning center and the milling centers are from the source [27].

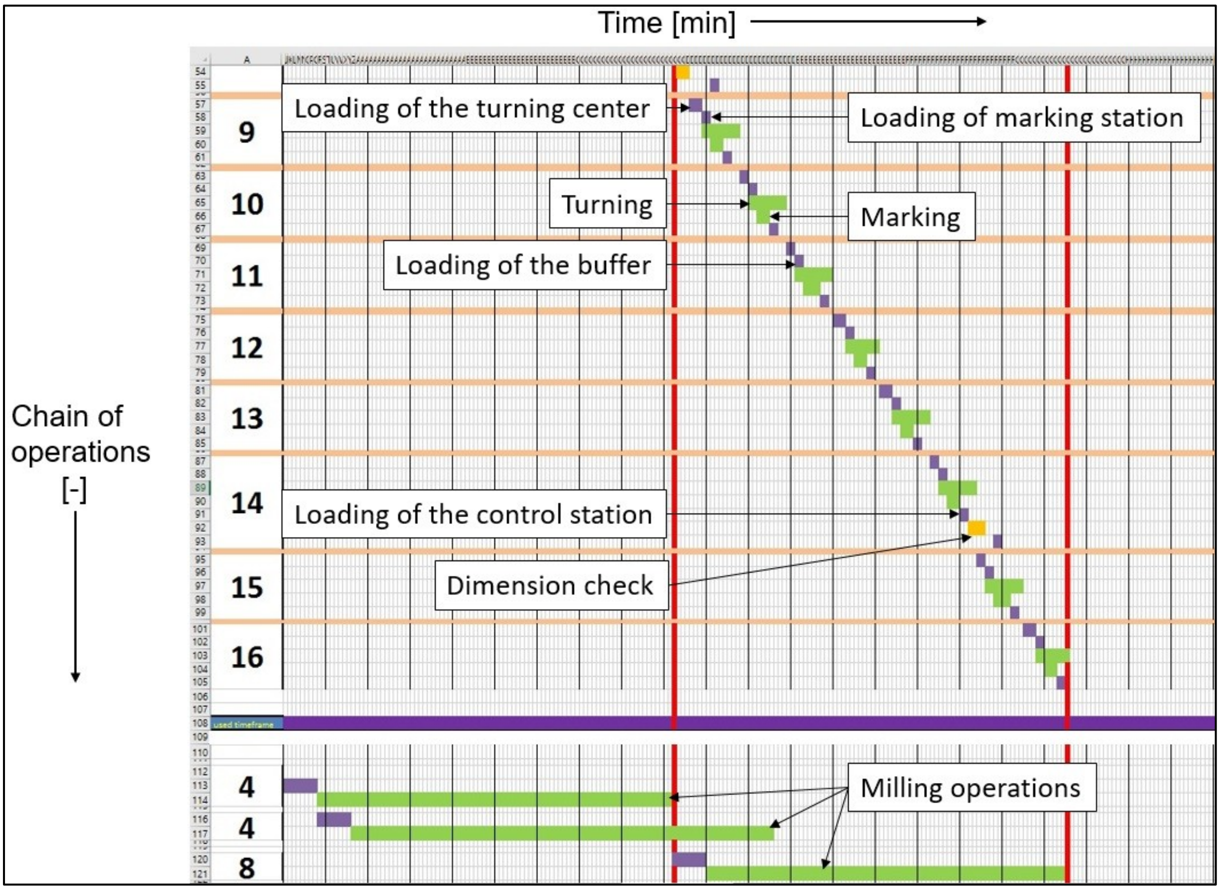


Fig.29 A part of a Gantt chart of the turning operations (upper half of the figure) and milling operations of the fourth configuration. In green are marked the machine operation, in purple the operations of the robot and in yellow the time of dimension controlling.

Fig. 29 shows the steps of the production operations, the upper half show the turning operation and the bottom part shows the milling operations. These operations run in parallel and the figure shows the exact time plot. On the left side of the figure are marked the numbers of the machined parts from each new batch. This part of the graph was chosen to demonstrate that at the end of one milling cycle of the A cams, marked in red, there are 7 turned parts finished. This leads to accumulation of 3 cams after each milling cycle. The accumulation of the cams increases with the increasing number of milling cycles, because almost 8 cams are finished turning at the end of one milling cycle. The orange horizontal lines separate the machining cycles one from each other.

The main disadvantage of this configuration is a decreased productivity of the cell, compared to the configuration #3 where almost 10 cams are finished turning while one milling cycle ends. On the other hand, the improvements are less manipulation leading to a smaller probability of clamping errors and less space consumption, which is always an advantage because of the limited workhouse space. This can be used to implement a secondary control station as shown on fig. 28., or to use the free space for other needs such as stock of the accumulated parts for example.

3.2.5 Configuration #5

In this solution, the currently used vertical lathe is replaced by one new vertical turning machine FAMAR Tandem described in chapter 3.2.1.2. The milling centers could be again replaced by the NHX 5000 described in chapter 3.2.2.1. The choice to keep the current milling centers or to replace them with new ones can be made based on the investment analysis in chapter 4.7. Two robots IRB 4600 are used, the technical details can be found in Annex 1. The first one for operating the turning center and second one for operating the milling centers, similarly to the configuration #4.

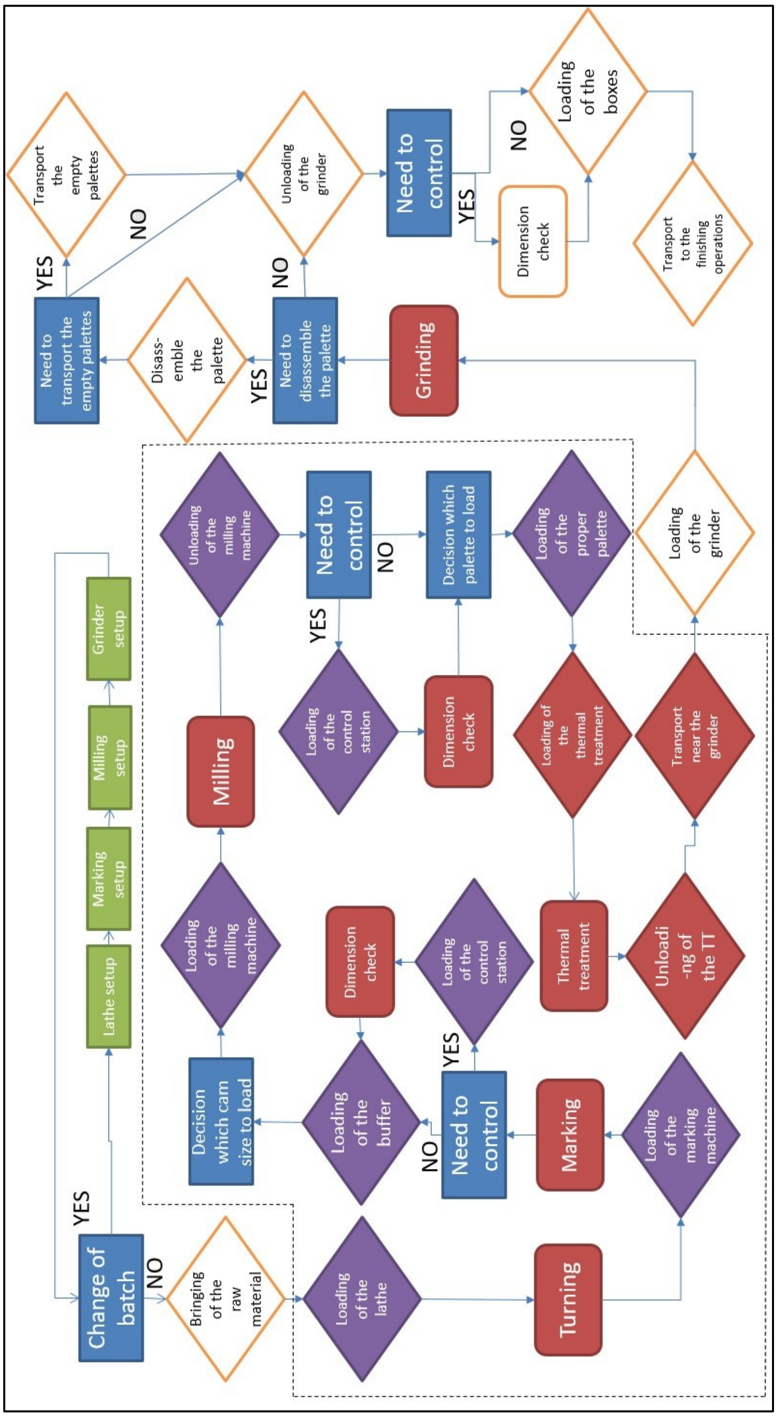


Fig.30 Workflow of the fifth proposition, the used symbols are similar to those in the fig. 27.

A semi-automatic turning center with a conveyor is used in this configuration. Loading of the entry conveyor is done by a robot, using the same technology as in chapter 3.2.4. The machine has two separate conveyors, one for entry of the raw work-pieces and the second to carry out the machined parts. On each of the two conveyors are prepared fixtures for the cams, these fixtures are adjustable for different cam sizes and have to be prepared in advance by the operator. Another option is to equip the conveyor with universal fixtures that would not need to be adjusted for different cam sizes. The robot loads the raw work-piece from the palette into the fixture, which is then transported to the first machine spindle. The spindle automatically picks up the work-piece and the first side is turned. Afterwards, the spindle passes the semi-machined work-piece to a second spindle where the rest of the turning operation is done. The machined cam is then loaded into a fixture on the second conveyor, which brings it into the radius of the robot. The rest of the operations are the same as in the configuration #4. A secondary control station can be installed like in the previous proposition, but due to the bigger dimensions of the turning center it does not fit in the same position but has to be moved behind the turning center, as shown on fig. 31.

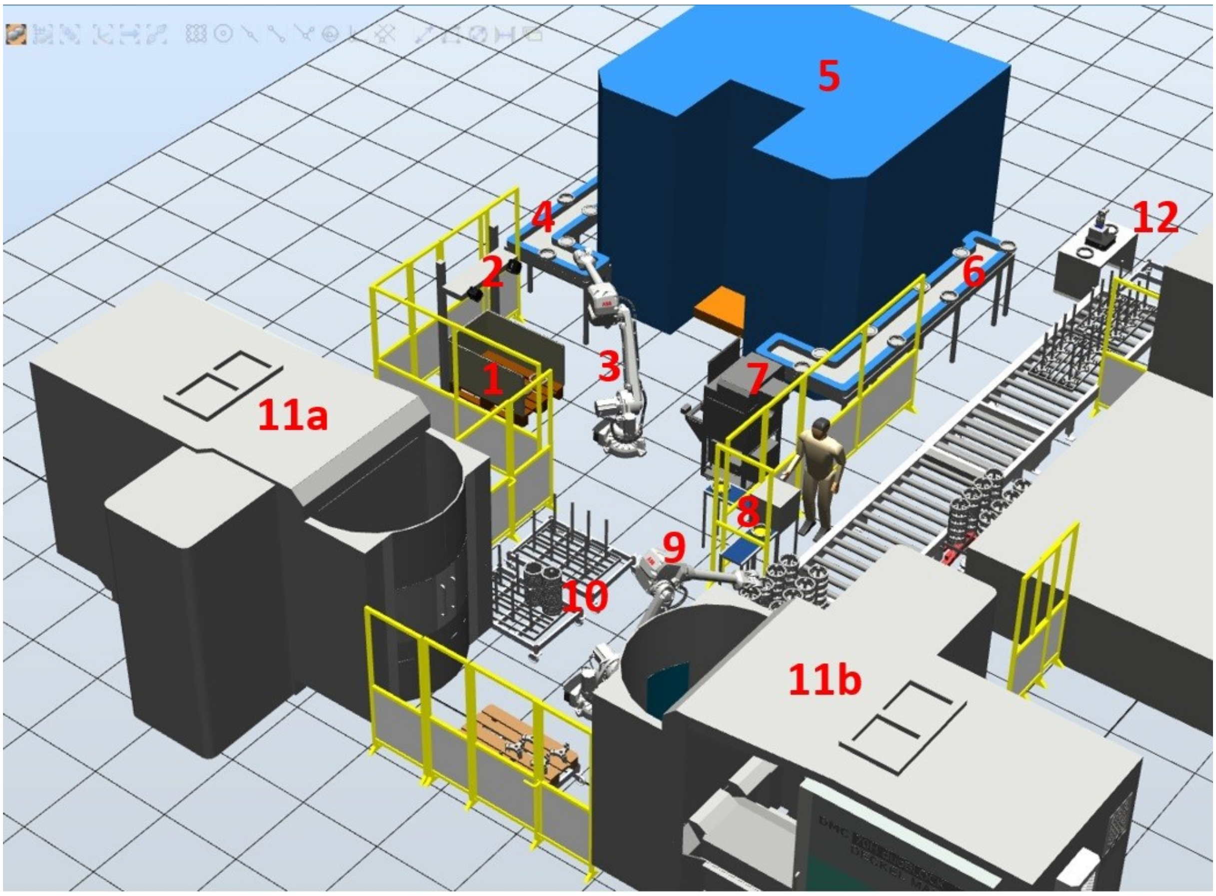


Fig.31 3D model of the configuration #5 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 12.

In the fig.31 the references are the following:

- 1 – palette with the raw work-pieces,
- 2 – 3D camera vision for automated picking of the raw work-pieces,
- 3 – first robot operating the turning center,
- 4 – entry conveyor of the turning center,
- 5 – turning center FAMAR Tandem 415,
- 6 – output conveyor of the turning center,
- 7 – marking machine,
- 8 – control station for basic characteristics controlling,
- 9 – second robot operating the milling centers,
- 10 – buffers for different cam sizes,
- 11 – milling centers,
- 12 – control station for special characteristics controlling.

The models of the machines used in the model do not correspond exactly to the machines that will be used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine, operator and the milling centers are from the source [27].

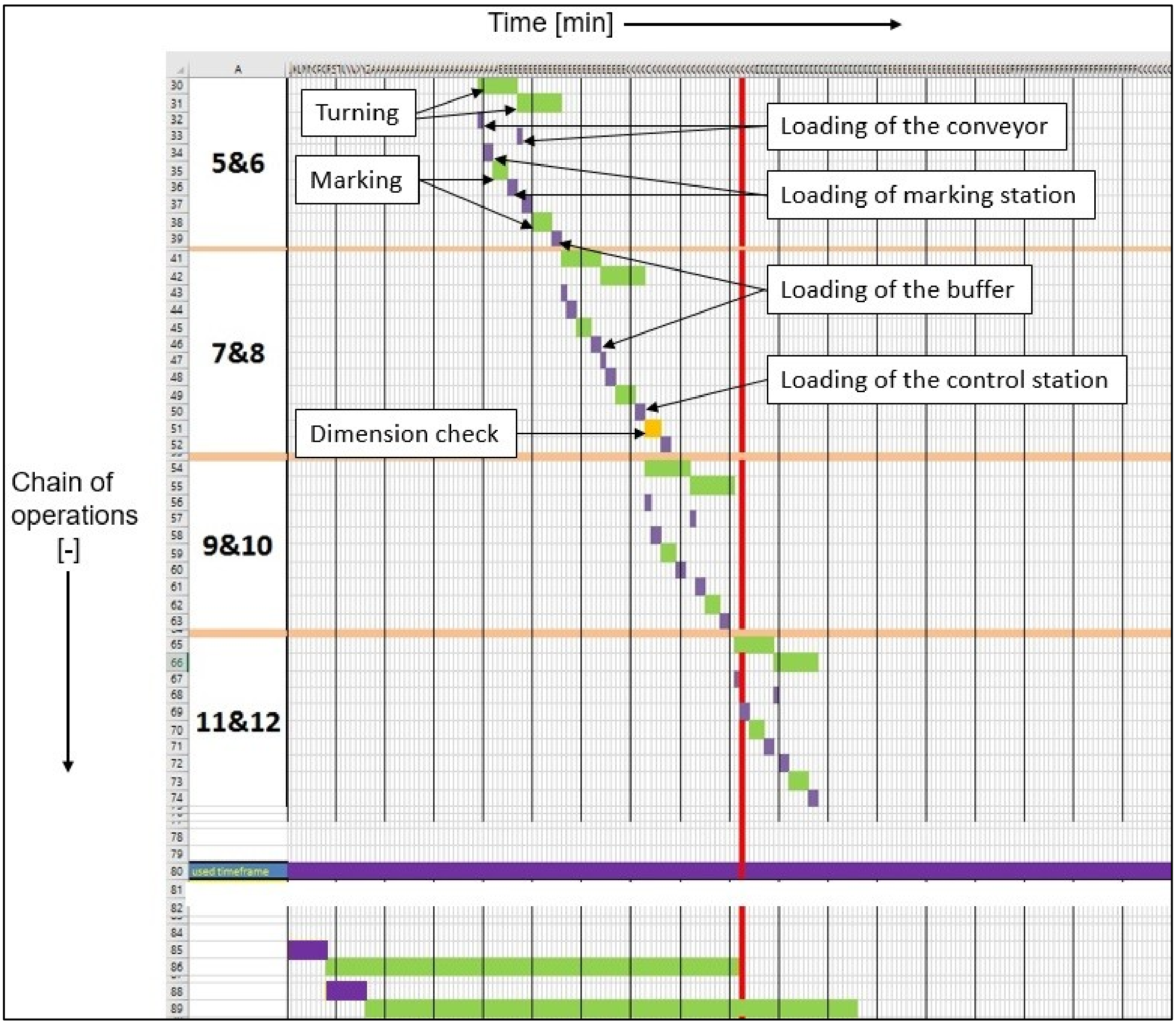


Fig.32 A part of a Gantt chart of the turning operations (upper half of the figure) and milling operations of the fifth configuration. The marking is the same as in fig. 29.

Fig. 32 is similar to the figure 29, it shows each step of the turning operations and the red line marks the end of the milling cycle. Based on the graph, 9 cams are finished turning at the end of the milling cycle. Comparing to the previous configuration, the productivity of the turning center has been raised by 50 %. This means the buffer for the turned parts must be enlarge to the capacity of 150 cams, in order to cover the accumulation of the cams during one 8 hours long shift. The other option is to reorganize the configuration and add a third milling center. This opens the possibility to invest in only one new milling center instead of two, and to improve the overall productivity of the cell.

The time of manipulation is significantly decreased by using of the conveyor. This semi-automatic solution allows to use only one robot for all the necessary operations and to improve the productivity at the same time. Other big advantage is the precision, the cams are loaded by a 1-ax handler so the risk of trajectory errors is decreased [39]. According to the technical information of the producer, the adjustment time for different cam sizes should vary around 12 minutes, which is also an improvement comparing to the current situation. In addition to that, the stamping process could be implemented directly onto the conveyor, reducing the operations of the robot and its deterioration.

The disadvantage of this solution is a complicated access to the turning center control panel, which is located in the middle of the front face of the machine, so it is impossible for the operator to reach it without stopping the whole turning process. Due to the higher productivity of the turning center, the palette with the raw work-pieces is emptied before the end of the working shift. The operator must intervene and change the palette, which causes a delay of the production because the robot must be stopped for safety reasons. This problem can be solved by installing an additional 3d vision system for a second palette, the economic impact is discussed in chapter 4.7.

3.2.6 Configuration #6

This solution is similar to the configuration #5, the only difference is that a different turning center is used. Instead of one vertical lathe, two pieces of Doosan Puma V8300 are used. Compared to the configuration #3, the two lathes are placed next to each other to decrease the time of manipulation. Their technical details can be found in chapter 3.2.1.1. The milling centers could be again replaced by the NHX 5000 described in chapter 3.2.2.1. The choice to keep the current milling centers or to replace them with new ones can be made based on the investment analysis in chapter 4.8.

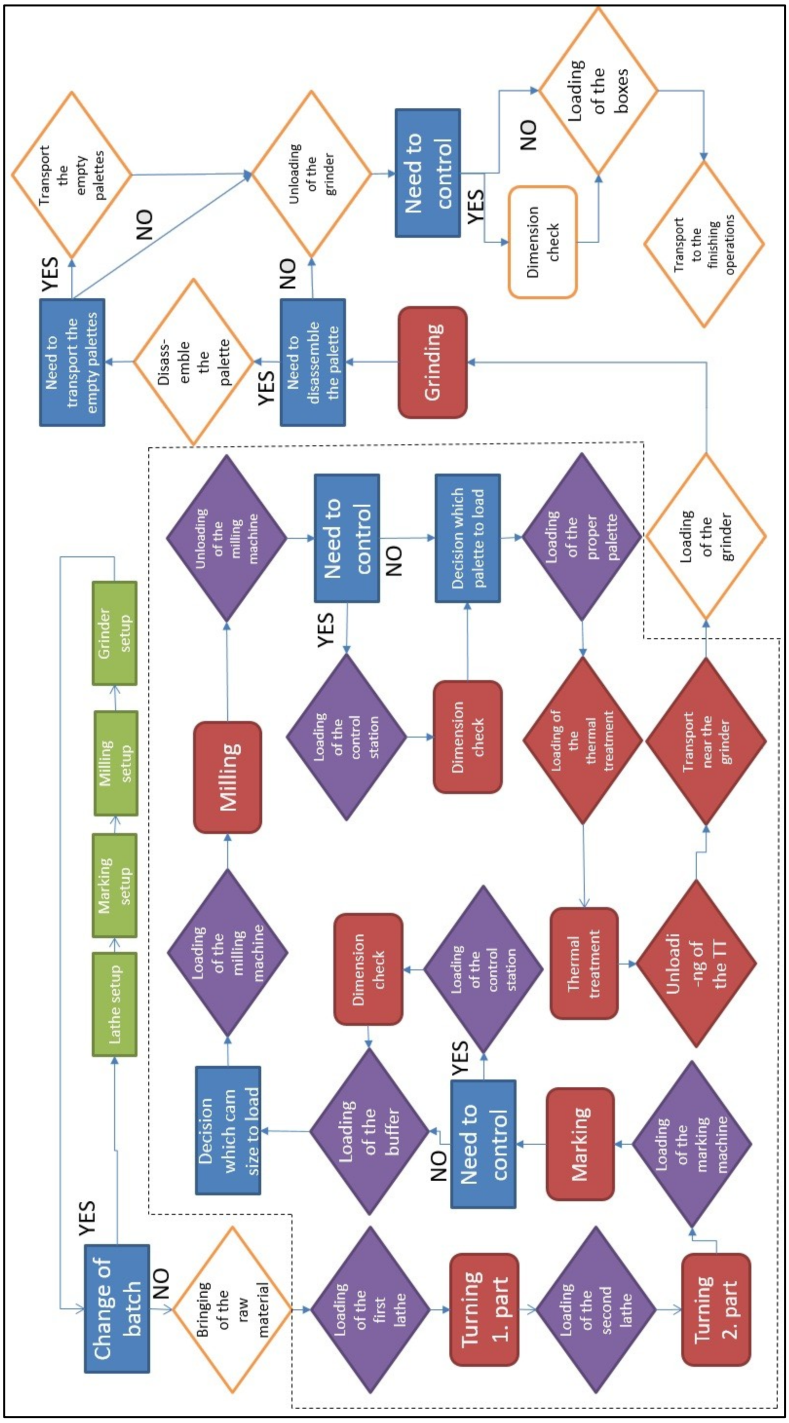


Fig.33 Workflow of the sixth proposition is the same as the workflow of the configuration #3.

The fabrication process of this configuration is very similar to the configuration #3 discussed in chapter 3.2.3. The differences are less space consumption because the turning centers are vertical, therefore they can be placed next to each other without any loading problems and the time of manipulation is decreased.

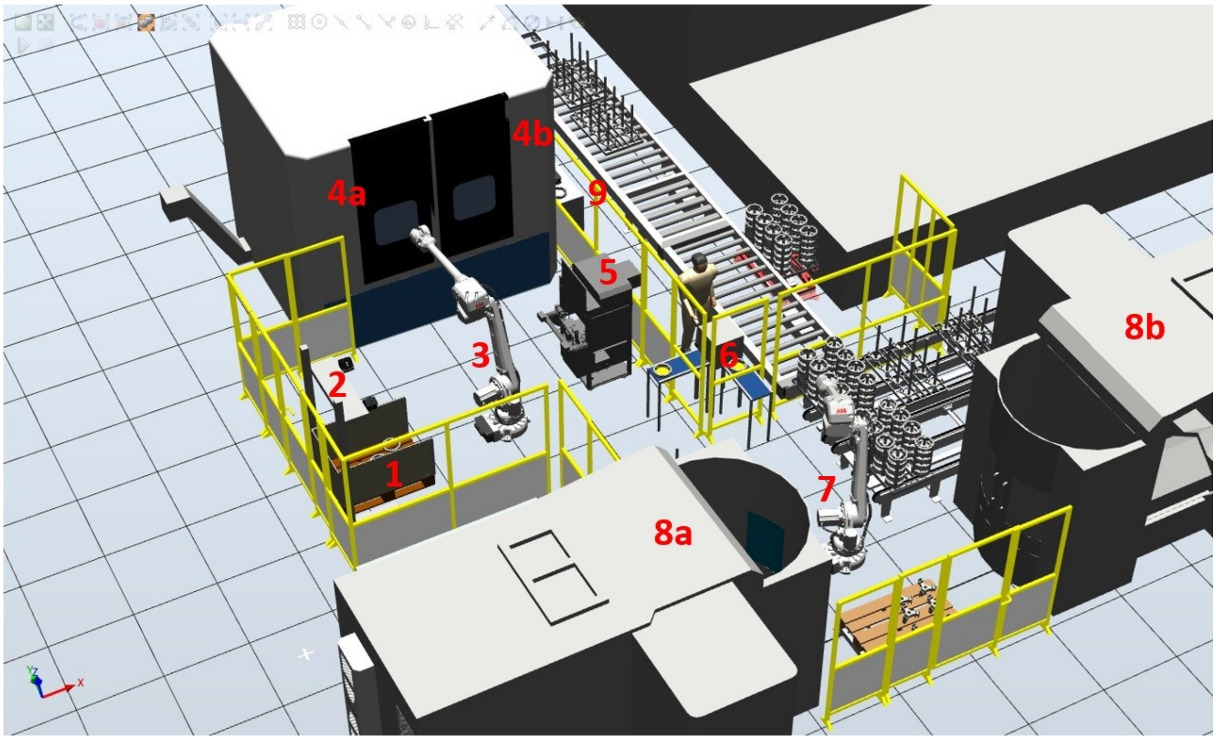


Fig.34 3D model of the configuration #6 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 13.

In the fig.33 the references are the following:

- 1 – palette with the raw work-pieces,
- 2 – 3D camera vision for automated picking of the raw work-pieces,
- 3 – first robot operating the turning center,
- 4 – turning centers Doosan Puma V8300,
- 5 – marking machine,
- 6 – control station for basic characteristics controlling,
- 7 – second robot operating the milling centers,
- 8 – milling centers,
- 9 – control station for special measurements.

The models of the machines used in the model do not correspond exactly to the machines that would be used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine, operator and the milling centers are from the source [27].

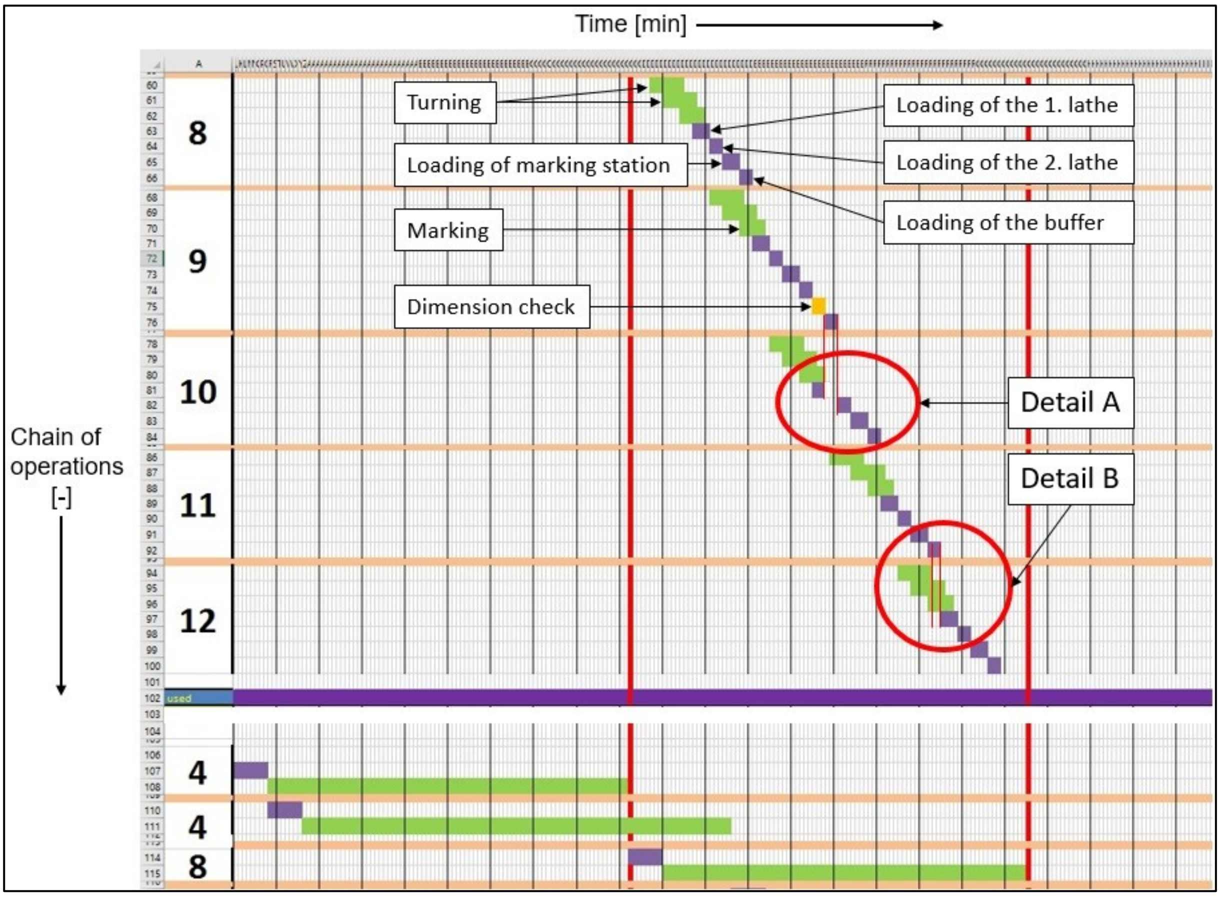


Fig.35 A part of a Gantt chart of the turning operations (upper half of the figure) and milling operations of the sixth configuration. The marking is the same as in fig. 32.

Fig. 35 is showing each step of the turning operations for configuration #6, the red line marks the end of the milling cycles for the cams that are also turned, and not loaded from the stock buffer. Detail A marks the slow-down of the process due to the dimension controlling of each 7. turned cam. This shows that the robot is used up to its full capacity. The time of manipulation for each operation is calculated with a reserve, to cover the realistic variations of the process.

Even though there are two separate turning centers each machining one side of the cam, their productivity is relatively low. It is caused by the excessive number of operations executed by the robot. For example, the loading of the 1. lathe could have been done directly after the first turning operation is finished, however the fig. 35 shows that it is not possible because the other handling operations provided by the robot have not been finished yet. This creates the idle time shown on detail B, slowing all the fabrication process.

Like in the configuration #4, a bottleneck is created due to the productivity of the milling centers, which is still lower than the productivity of the turning centers. Two cams are accumulated during each milling cycle, so a buffer with the capacity of 70 work-pieces is needed to cover the accumulation of the cams during one 8 hours long working shift.

3.2.7 Configuration #7

This solution is completely different from all the configurations proposed so-far. The turning and milling machines are replaced by new mill turn centers DMG Mori NT4250 discussed in detail in chapter 3.2.2.2. This leads to a complete change of the layout, workflow and production rate. A bigger robot – IRB 6640 – is used for operating of the mill turn centers, its technical details can be found in Annex 15. The second robot for loading of the cams into the palettes for thermal treatment is the IRB 4600, which was used in the previous configurations.

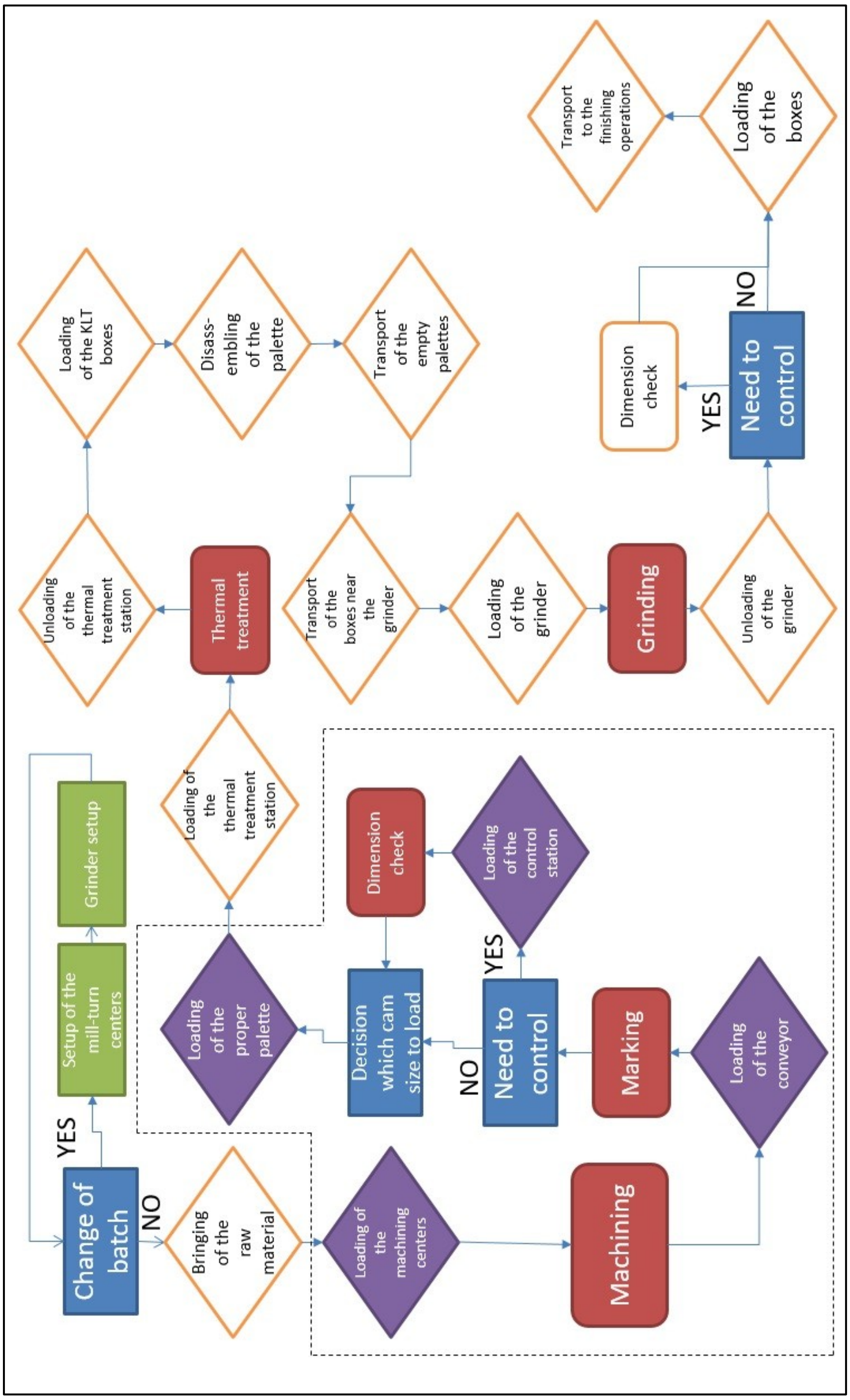


Fig.36 Workflow of the seventh proposition, the used symbols are the same as in the fig. 30.

Loading of the turn-mill centers is done similarly to previous configurations, where the operator brings the palettes to a designated place from where the robot automatically loads them, using a 3D vision system. The turning and milling operations are done by the same machine so the time of manipulation with the work-pieces is significantly reduced. The centralization of the machining operations allows to organize the fabrication cell more efficiently with small distances between the robot and the machines. The first robot executes only two operations – loading and unloading of the machining centers, the secondary operations such as marking and dimension control are provided by the second robot, or implemented onto a conveyor as in configuration #1 discussed in chapter 3.1.1.

The fabrication process can be adapted to the production of different cam sizes more easily, because there is only one machine setup required. Each of the three machining centers can be setup to machine a different cam size and these operations can run in parallel. Three different palettes can be placed in the loading area allowing a flexible production, however a 3D vision camera system has to be installed over every palette to allow their loading, which increases the required investment. In every case, the price for this configuration will be much bigger than for the previous configuration because of a completely new machine park, need of a bigger robot and multiple 3d vision systems. The investment details are discussed in detail in chapter 4.9.

The mill turn centers dispose with 2 spindles that can work independently, so two different work-pieces can be machined in parallel in every machine. After the machining operations are finished, the cams are loaded onto a conveyor bringing them to the second part of the fabrication cell. A marking machine is implemented onto the conveyor. This machine communicates in real-time with the machining centers and the first robot and automatically recognizes which cam size is passing through it, so it marks it correctly.

Afterwards, the marked cams continue on the conveyor to the radius of the second robot. The end part of the conveyor is modified and divided into three separate lines. This system is proposed to stock different cam sizes on a separate conveyor, to simplify the size recognition to the second robot. From here, the second robot loads the cams into the palettes for thermal treatment or to the control station if needed. After the palettes are fully loaded, they are manually transported to the thermal treatment station. Automation of the rest of the fabrication process is not considered.

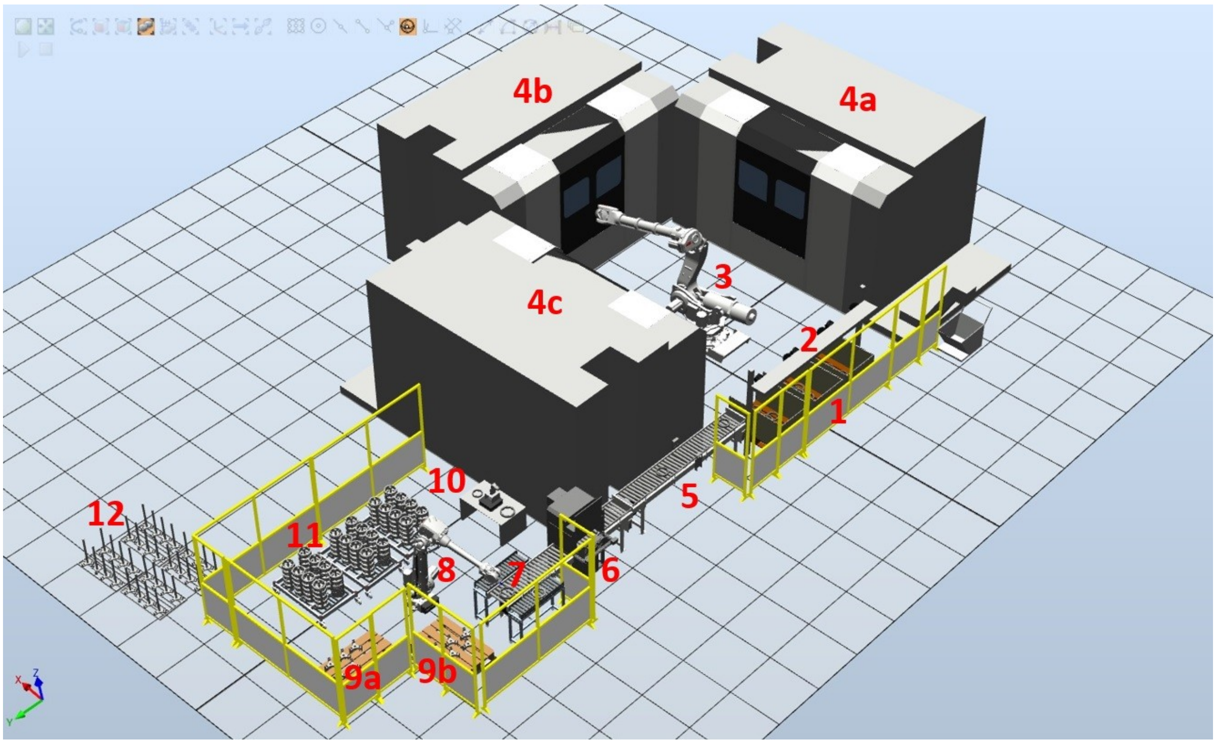


Fig.37 3D model of the configuration #7 created in ABB RobotStudio 6.05 and Autodesk Inventor Professional 2017; more images of this configuration can be found in Annex 14.

In the fig.37 the references are the following:

- 1 – palettes with the raw work-pieces,
- 2 – 3D camera vision system for automated picking of the raw work-pieces,
- 3 – first robot operating the mill turn centers,
- 4 – mill turn centers DMG Mori NT4250,
- 5 – conveyor for transportation of the machined cams,
- 6 – marking machine,
- 7 – three-part end of the conveyor,
- 8 - second robot loading the palettes for thermal treatment,
- 9 – stock of different centering fixtures,
- 10 - control station for basic characteristics controlling,
- 11 – palettes for the thermal treatment,
- 12 – prepared empty palettes.

The models of the machines used in the model do not correspond exactly to the machines that will be used, however the dimensions are similar so the model respects the real usable workspace. The models of the marking machine is from the source [27].

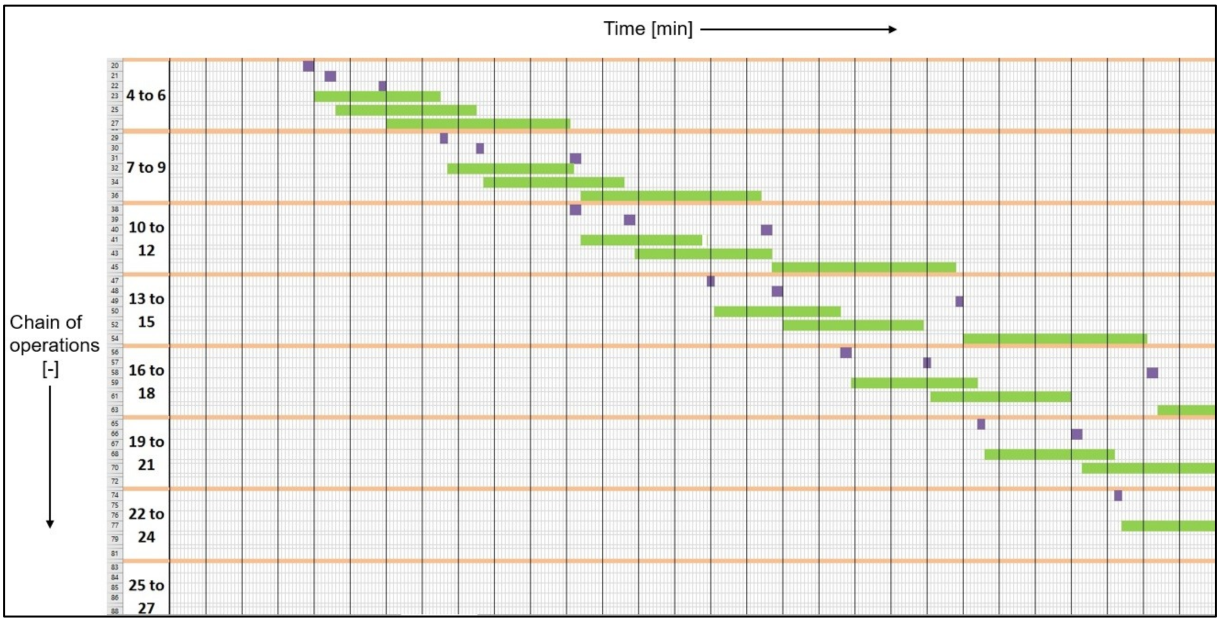


Fig.38 A part of a Gantt chart of the operations of the seventh configuration, setup for production of three different cam sizes in parallel. In green are marked the machining operations and in purple the manipulation operations.

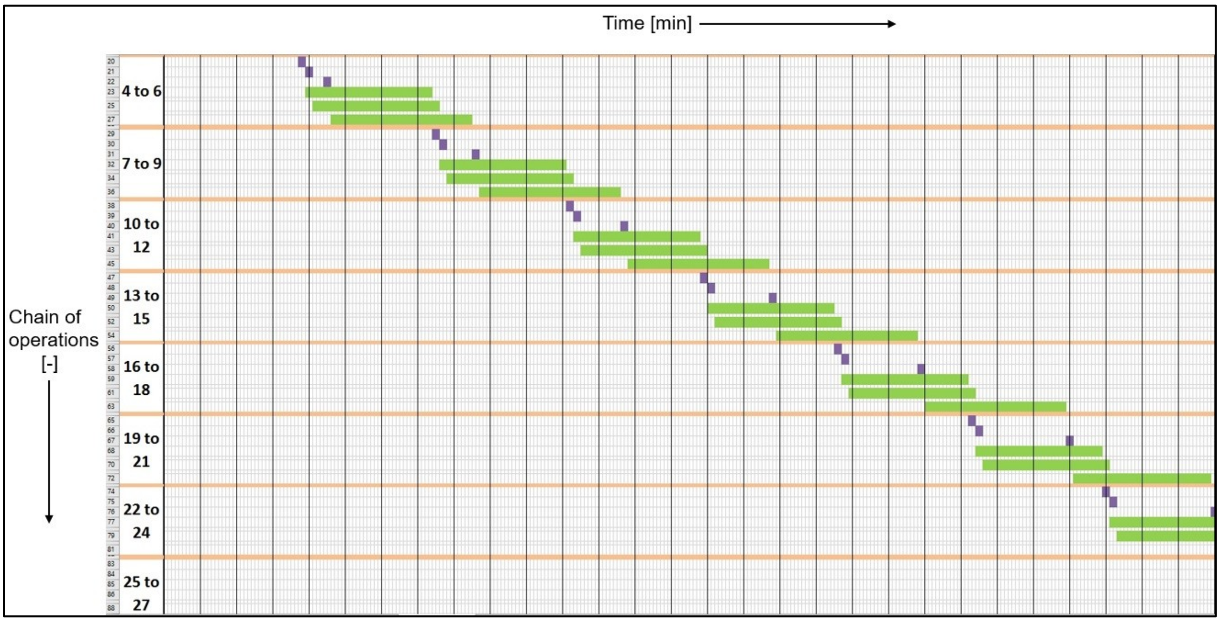


Fig.39 A part of a Gantt chart of the operations of the seventh configuration, setup for production of one cam size on two machines and a second cam size on the third machine. In green are marked the machining operations and in purple the manipulation operations.

These two figures compare the production steps related to the time for the same configuration but for two different setups. They show that the first setup becomes much more disorganized with the rising number of machining cycle, while the second stays relatively the same. According to these two graphs, it is suggested to plan the production of only two different cam sizes in parallel and to change them more often, rather than to produce three different cam sizes and disrupt the continuity of the process.

This configuration may be the easiest to implement, because of the completely new machine park. The layout is completely new, therefore it can be more easily adapted to any constraints discussed in chapter 2.5. The new machine park is also favorable for the software communication between the machines, robots and other automated systems.

Thanks to the integration of two machining operations into one, the time of manipulation with the work-pieces is reduced to a fraction of the total time compared to some configurations. Less manipulation leads to less clamping errors and there is no need of modification of the clamping fixtures. Moreover, there is no need for temporary stock buffers like it was needed in the previous configurations. The machined parts are directly loaded in the palettes for thermal treatment but it is possible to implement a safety buffer in case of an unexpected error with the loading of the palettes.

The production is more continuous but on the other hand, it is slower than in all of the previous configurations. For example, if this configuration is compared to the configuration #5, the productivity of the fabrication cell as a whole is only 30%. In addition to that there is accumulation of the turned cams in the configuration #5, because of the high productivity of the turning center. This means that the productivity of this configuration is even smaller. In addition to that, this configuration includes more complex technical solutions and depends more on the software and real-time communication. Due to this fact, the required financial investment can be much higher but especially, it complicates the resolution of an unexpected technical problem and can lead to a longer idle time of the fabrication cell than in previous configurations.

4 INVESTMENT ANALYSIS

The economic factor is one of the most important, when it is needed to decide about a long-term investment. Therefore, an economic justification is required. The range of investment is related to the diversity of the product. The more products are to be produced on an automated production line, the more tools and different operations need to be implemented which leads to increase of the investment [40].

There is a large variety of robot producers and companies dealing with automation of the production. Each company has its own price for a specific service or product but even though, there are many similarities. The analysis in this chapter will not specify the company names, all the stated costs were calculated as an average value.

This is a simplified analysis discussing only the biggest savings and investments needed for each configuration. Besides the investments and savings stated in the tables bellow, there are several other related to a complete installation of the automated fabrication cell. However, the other investments and savings are relatively low and do not affect the final price significantly. This analysis deals only with the rough propositions that would be detailed later. All the prices in the investment tables are stated without the value-added tax. The prices for the robots and the machining centers include all expenses required to make them fully operational. The number of the operator expresses the number of saved operators per 3 consequent 8 hours long working shifts equal to one working day.

The operator´s salary in the table of savings corresponds to a gross wage, the taxes correspond to the difference between the gross wage and the total labor costs according to the source [41]. The wages are calculated for a basic situation, without any allowances. The rest of the expenses include alimentation allowance, payed vacations and equipment provided by the employer.

4.1 Configuration #1a

The time of return of the investments of the configuration #1a – using of the current machining centers – is discussed in this chapter.

Tab. 4.1.1 Investments for the configuration #1a.

<table>
<tr><th></th><th>Type</th><th>Quantity</th><th>Price [€]</th><th>Total price [€]</th></tr>
<tr><td>Machining centers</td><td>-</td><td>0</td><td>0</td><td rowspan="6">411,000</td></tr>
<tr><td>Other machines</td><td>Marking machine</td><td>1</td><td>40000</td></tr>
<tr><td>Robots</td><td>IRB 4600</td><td>1</td><td>165000</td></tr>
<tr><td>Robot equipment</td><td>-</td><td>0</td><td>0</td></tr>
<tr><td rowspan="2">Other modifications</td><td>Conveyors</td><td>1</td><td>6000</td></tr>
<tr><td>Hydraulic clamping</td><td>2</td><td>100000</td></tr>
</table>

Tab. 4.1.2 Savings for the configuration #1a.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	3	7353	34836
Taxes		2589	
Other expenses		1670	

The return of the investment can be calculated with the following equation from the source [8]:

$$RI = TP \div S \text{ [years]} \tag{4.1.1}$$

where: RI [years] - time of return of the investment,
TP [€] - total price of the investment,
S [€] - total savings.

After applying the concrete values from the tables 4.1.1, 4.1.2 the time of return of the investment is 11.8 years. The usual time of return of the investment for the innovation projects should be shorter than 6 years [40], which means that this configuration is not profitable from this point of view. However, the automation of the production process has several different impacts that are not discussed in this thesis because of the confidentiality of the information, such as potentially increased production rate or an improved status of the company in the eyes of the customers.

4.2 Configuration #1b

The time of return of the investments of the configuration #1b – using of the current turning center and new milling centers – is discussed in this chapter.

Tab. 4.2.1 Investments for the configuration #1b.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	NHX 5000	2	350000	1061000
Other machines	Marking machine	1	40000	
Robots	IRB 4600	1	165000	
Robot equipment	-	0	0	
Other modifications	Conveyors	1	6000	
	Hydraulic clamping	2	50000	

Tab. 4.2.2 Savings for the configuration #1b.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	3	7353	34836
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the table 4.2.2, the result is 30.5 years which means that this configuration is highly non-economical.

4.3 Configuration #2a

The time of return of the investments of the configuration #2a – using of the current machines and two robots – is discussed in this chapter.

Tab. 4.3.1 Investments for the configuration #2a.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	-	0	0	701000
Other machines	Marking machine	1	40000	
	Control station	1	80000	
Robots	IRB 4600	2	165000	
Robot equipment	Motion rail	1	60000	
Other modifications	Conveyors 1	2	6000	
	Conveyors 2	1	15000	
	Hydraulic clamping	2	100000	

Tab. 4.2.2 Savings for the configuration #2a.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.3.1 and 4.3.2, the result is 10 years. This configuration has a potential to be developed more in detail and considered as realizable.

4.4 Configuration #2b

The time of return of the investments of the configuration #2b – using of the new milling centers and two robots with a modification of the currently used lathe– is discussed in this chapter.

Tab. 4.4.1 Investments for the configuration #2b.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	NHX 5000	2	350000	1481000
Other machines	Marking machine	1	40000	
	Control station	1	80000	
Robots	IRB 4600	2	165000	
Robot equipment	Motion rail	1	60000	
	3D vision	1	30000	
Other modifications	Conveyors 1	2	6000	
	Conveyors 2	1	15000	
	Lathe modification	1	50000	
	Hydraulic clamping	2	100000	

Tab. 4.2.2 Savings for the configuration #2a.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.4.1 and 4.4.2, the result is 22.3 years. The time of return of the investment is long, however there are two investments at the same time – first into the automation of the production cell and second into the new machine park. This can be considered as two separate projects implemented at the same time, so the expected time of return would be longer than 6 years. In addition, the currently used machines will have to be renovated or replaced by the new ones, in the following years.

4.5 Configuration #3

The time of return of the investments of the configuration #3 – using of the new turning centers, current milling centers and two robots – is discussed in this chapter.

Tab. 4.5.1 Investments for the configuration #3.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	NLX 3000	2	190000	975000
Other machines	Marking machine	1	40000	
	Control station	1	80000	
Robots	IRB 4600	2	165000	
Robot equipment	3D vision	1	30000	
Other modifications	Conveyors	2	15000	
	Hydraulic clamping	2	100000	

Tab. 4.5.2 Savings for the configuration #3.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.5.1 and 4.5.2, the result is 14 years. Similarly to the configuration #2b, new machining centers are implemented in this solution so the time of return of the investment can be reasonable. In the case that new milling centers are also implemented in this configuration, the time of return of the investment would be 22.6 years.

4.6 Configuration #4

The time of return of the investments of the configuration #4 – using of a new turning center, current milling centers and two robots – is discussed in this chapter.

Tab. 4.6.1 Investments for the configuration #4.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	NZX 2000	1	400000	1190000
Other machines	Marking machine	1	40000	
	Control station	2	80000	
Robots	IRB 4600	2	165000	
Robot equipment	3D vision	1	30000	
Other modifications	Conveyors	2	15000	
	Hydraulic clamping	2	100000	

Tab. 4.6.2 Savings for the configuration #4.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.6.1 and 4.6.2, the result is 17 years. As in the previous configuration, new machining centers are implemented in this solution so the time of return of the investment can be reasonable. In addition, the investment counts with a secondary control station. In the case that new milling centers are also implemented in this configuration, the time of return of the investment would be 27.1 years.

4.7 Configuration #5

The time of return of the investments of the configuration #5 – using of a new semi-automatic turning center, current milling centers and two robots – is discussed in this chapter.

Tab. 4.7.1 Investments for the configuration #5.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	Tandem 415	1	670000	1460000
Other machines	Marking machine	1	40000	
	Control station	2	80000	
Robots	IRB 4600	2	165000	
Robot equipment	3D vision	1	30000	
Other modifications	Conveyors	2	15000	
	Hydraulic clamping	2	100000	

Tab. 4.7.2 Savings for the configuration #5.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.7.1 and 4.7.2, the result is 21 years and in case of implementation of the new milling centers it is 29.6 years.

4.8 Configuration #6

The time of return of the investments of the configuration #6 – using of the new vertical turning centers, current milling centers and two robots – is discussed in this chapter.

Tab. 4.8.1 Investments for the configuration #6.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	Puma V8300	2	240000	1090000
Other machines	Marking machine	1	40000	
	Control station	2	80000	
Robots	IRB 4600	2	165000	
Robot equipment	3D vision	1	30000	
Other modifications	Conveyors	2	15000	
	Hydraulic clamping	2	100000	

Tab. 4.8.2 Savings for the configuration #6.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.8.1 and 4.8.2, the result is 15.6 years and in case of implementation of the new milling centers it is 26.8 years.

4.9 Configuration #7

The time of return of the investments of the configuration #7 – using of the new mill turn centers and two robots – is discussed in this chapter.

Tab. 4.9.1 Investments for the configuration #7.

	Type	Quantity	Price [€]	Total price [€]
Machining centers	NT 4250	3	700000	2685000
Other machines	Marking machine	1	40000	
	Control station	1	80000	
Robots	IRB 4600	1	165000	
	IRB 6660	1	180000	
Robot equipment	3D vision	3	30000	
Other modifications	Conveyor	1	30000	

Tab. 4.9.2 Savings for the configuration #7.

	Number of saved operators	Savings [€] /year	Total savings [€] /year
Operator´s salary	6	7353	69672
Taxes		2589	
Other expenses		1670	

Using the same equation for the calculation of the time of return of the investment as in the previous configuration, but applying the values from the tables 4.9.1 and 4.9.2, the result is 38.5 years.

5 DISCUSSION

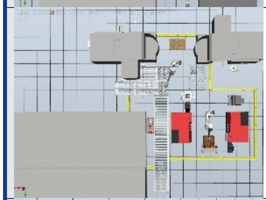
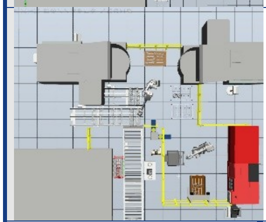
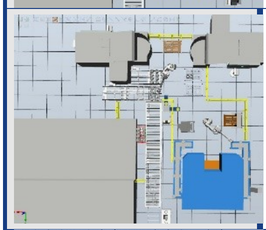
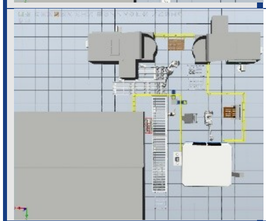
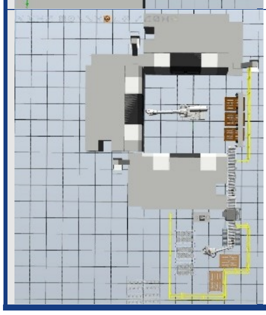
Modernization and improvement of the fabrication process are very important factors for every company to maintain its competitiveness with the concurrence. Optimization of the production process, reduction of the machining time, elimination of the secondary operations and financial savings are the keys of success. The technological aspects of the machining of the cams within PH in Brno is already well optimized for the current machine park. After the analysis of the current fabrication process, several possibilities of improvement have been observed.

The fabrication consists of various machining operations that require many secondary operations, which are currently being executed by the operator. For example, cleaning of the work-pieces of the chips and the coolants could be automated by integration of an air-blowing system into the machines. The deburring after the milling operation can be automated by implementation of a special deburring tool at the end of this operation. Automated adjustment of the conveyor for different cam sizes and automated marking would save a lot of operator's time. The dot peen marking machine can be replaced by a laser marker, which works faster. Currently, the operators fill in the papers about the status of the machined cams after each operation. This includes the results of the dimension controlling, the timetable of the operations and many more. Using of an electronic recording of these operations would make it easier for monitoring, tracing and controlling.

Even though this thesis does not discuss the automation of the second fabrication cell of the cams, its current fabrication process has been analyzed. The cell includes two different machining operations – grinding of the curve and honing. There are two grinders, each with a rotary table similar to the milling machines discussed in chapter 2.1.2. That means the work-piece on one side of the table is being machined while there is a second work-piece mounted by the operator on the second side of the table. Contrary to the milling operation, only one work-piece is mounted and machined at a time. However, there exists the possibility to develop a new fixture able to hold two work-pieces at a time, placed at each other. The grinding tool is long enough to machine both cams at the same time. This solution is limited by two main factors – the power of the machine and the bending of the grinding tool. The company has a third available grinder that is currently not operating. This is caused by the fact that this grinder does not have a rotary table, so the productivity would be significantly lower than on the two others. A second problem with this machine is the danger of inhaling the chemical vapors by the operator while he is changing the work-pieces. A solution for this problem may be the implementation of a robot operating this third grinder, which would increase the capacity of the grinded cams.

The company's main objectives are to automate their production lines, because of the increasing problem with the lack of labor power. This may not be the case of the factory in Brno, however the automation project is currently being treated in other company´s subsidiaries so it is practical to handle it globally in different subsidiaries. Based on the PH´s requirements and discussion with the robot producers and automation integrators, seven different configurations for automation of the production cell are proposed. Each configuration has its pros and cons discussed in detail in the chapter 3, the tab. 5.1 sums them up. In addition to the information from the chapter 3 and 4, personal remarks and verbally communicated information are added to create a more complex evaluation of the possibilities.

Tab. 5.1 Summary of the proposed configurations.

	No.	Milling centers	TP [€]	RI [year]	Flexibility	Level of upgrade	Other facts
	#1	Old	411000	11.8	Very low	Low	Omitting important operations
		New	1061000	30.5	Very low	Medium	
	#2	Old	701000	10	Low	Low	Usage of a motion rail
		New	1481000	22.3	Medium	Medium	
	#3	Old	975000	14	Low	Medium	Robot no.1 is overloaded
		New	1575000	22.6	Medium	High	
	#4	Old	1190000	17	Medium	Medium	Lower production rate, but smaller risk of errors
		New	1890000	27.1	Medium	High	
	#5	Old	1460000	21	High	Medium	Compact and effective, but longer delivery time
		New	2063000	29.6	High	High	
	#6	Old	1090000	15.6	Medium	Medium	Robot no.1 is overloaded
		New	1870000	26.8	Medium	High	
	#7	-	2685000	38.5	Very high	Very high	Changed layout and material flow, low productivity

Tab. 5.1 shows the total price of investment, time of return of the investment, flexibility and level of modernization for different configurations. It includes two options for each configuration, in the first one are used the current milling centers and in the second are used the new milling centers described more in chapter 3. The level of flexibility presents the possibilities to adapt the production to different needs of the company´s assembly department. For example, to quickly change the size of the machined cams because of an increased demand of a specific type of motor. This coefficient also presents the possibility to machine completely different types of products. That is the reason why the configuration #7 has a very good coefficient. The machining centers used in this solution have a waste range of machining possibilities allowing to use them to produce work-pieces of various sizes and shapes. The configuration #5 has not the possibility to easily adapt the fabrication process for different types of work-pieces, however it has the shortest time of setup for different sizes of the cams.

The level of upgrade is also an important factor to be considered. Because the machines are constantly working, they start to get used and require more maintenance than the new machines. This results in a bigger financial investment into the machine and to an increased idle time because of their maintenance. The years of return of the investment are quite elevated, because only the financial savings on human work have been counted in. These information should be considered together with other factors stated in the table 5.1 or in chapter 3 for each configuration.

In general, two biggest problems have been discovered in the configurations using the current machine centers. Firstly, a big investment is required in the modification of the machines such as hydraulic clamping system or the software interface for the communication between the machines and the robots. Secondly, the safety regulations are evolving every year and are more and more strict. This emerges the problem with the older machines, that have been adapted to the regulations valid in the year of their construction. However, as the regulations changed and the modernized production cell should meet the current criteria, there exist a risk of not meeting them with the older machining centers.

Starting with the configuration #2 where the second robot is fixed on a motion rail, it may appear as a very good solution because of the increased operations that can be provided by the robot. After the discussion with different automation integrators, it is recommended to rather use 2 robots instead of one on a motion rail. The motion rail is very expensive, especially in bigger dimension like in this case, and is difficult for maintenance. Next the hidden problems of the configuration #3 are bigger space consumption, overloading of the robot because of many operations it need to execute and a longer cycle time. The cycle time of the machining is increased due to the need of precise loading of the work-pieces into the turning centers and due to the use of two centers for the turning, instead of one. The cycle time is increased also in the configuration #4 and in addition to that, the lathe used in this configuration is suitable for machining of the cams up to a certain size. The maximum possible turned size is smaller than the size of the cams that are needed to be machined.

The approach to the problem in this thesis is mostly analytic with regards to the technological facts and needs of the company. A simplified economical aspect was also discussed to give an idea of the approximate sum of money needed for this project. It is recommended to treat the problem regarding different aspects like logistic, organization and in-depth economics. This would give a different point of view on the situation, analyzing the different proposed configurations in more detail. Thanks to these analysis, the time of return of the investment may decrease significantly allowing the project to be approved by the management of the company.

As it was already stated, the project of automation is in progress not only in Brno but in other PH subsidiaries. Some factories are producing the same products, others are specialized in fabrication of different types of products like pumps, valves or different types of motors. The different subsidiaries treat the automation on their own, considering the elements that are crucial for them. However, the progress of the project and different solutions are always communicated to the other subsidiaries. This allows a faster progress of the project by avoiding the common mistakes. In addition to that, it was decided to choose a common robot producer for every PH plant. This results not only in a better price, but also in creation of a strong partnership between PH and the chosen robot producer. This can have many important benefits like priority service or valuable information about the fine-tuning of the automated workplaces.

CONCLUSION

This work deals with automation of a production cell of the cams – a part of the hydraulic motors fabricated within Poclain Hydraulics in Brno. The progress of the development of this thesis was influenced by realistic problems, choices and decisions. It was elaborated directly in the industrial environment and the propositions were modified several times to adapt the changing requirements. Each proposition includes a workflow chart showing all the operations and a detailed description of the production process with highlighted problems and advantages. In addition to that, a part of every proposal is also a render of a 3D model of the configuration and a commented part of a Gantt chart showing the timetable of the operation.

The configurations vary and develop different possibilities to demonstrate the variability of the final solution. Thanks to the implementation of several automation elements and different machining centers, many hidden problems are revealed. These problems can be discussed internally or with the external companies to obtain the appropriate efficiency and reliability of the automated production cell. A part of the work is also a simple economic analysis of the proposed configurations, showing the approximate amount of investment.

Automation of production in an already operating factory is a complex operation requiring rigorous planning. The calculated time of return of the investments seems to make the realization of this project impossible. This problem is caused by the need of a high flexibility of the automated production cell. To realize this or any similar projects, the company must concentrate on the increase of the production. Bigger production means bigger earnings, and bigger earnings mean faster return of the investment. Therefore, it is recommended to further develop the configurations #4, #5 and #6, which have the highest productivity. With the estimated selling price of 50€ per cam, only a 5% increase of the production per day would decrease the time of return of the investment to only 5 years for the configuration #5. Adding to it the price of space per m^2 in the factory and the factor of modernization, the project becomes realizable.

This thesis gathers and resumes the information about automation of a flexible production and can be beneficial for any company starting a new project of automation. It shows, that an ideal configuration must be highly productive and consume the least space possible. Also, the companies must not fear a higher investment. It is more suitable to develop a completely new automated production line and to make use of the older machines for other operations in the factory.

Together with the described facts for each configuration, this work serves as a background source of information for the company. The information can be communicated within PH´s different subsidiaries and make the start of automation projects easier and more transparent.

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LIST OF USED SYMBOLS AND ABBREVIATIONS

Symbol	Unit	Description
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CNC	-	Computer Numerical Control
HMI	-	Human Machine Interface
HST	-	Hydrostatic transmission
OEE	-	Overall Equipment Efficiency
PPM	-	Parts Per Million
QR	-	Quick Response
WIP	-	Work In progress
WW1	-	World War One
D_v	L	Displacement
F	N	Resultant force
F_N	N	Normal force
F_t	N	Maximum vehicle traction force
F_T	N	Tangential force
N	Min^{-1}	Theoretical output speed
P_C	W/t	Corner power required for driving a vehicle
P_H	W/t	HST corner power
Q	L/min	Flow of the fluid
Q_A	L/min	Actual flow of the fluid
Q_T	L/min	Theoretical flow of the fluid
RI	year	Time of return of the investment
S	€	Total savings
S_e	m^2	Static area
S_g	m^2	Gravitation area
S_t	m^2	Total available workspace
S_v	m^2	Space allowing movement
T_A	Nm	Actual torque
T	Nm	Theoretical output torque
TP	€	Total price of the investment
k	-	Factory factor
n	-	Number of entrances in the production cell
η_o	-	Overall efficiency of the motor
η_{of}	-	Overall efficiency of the final drive
η_m	-	Mechanical efficiency
η_v	-	Volumetric efficiency
Δp	MPa	Pressure drop
α	°	Angle between F and F_N
ρ	mm	Distance between the center of the contact ball and the base of the piston

LIST OF ANNEXES