VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

BRNO UNIVERSITY OF TECHNOLOGY

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ

ÚSTAV ELEKTROTECHNOLOGIE

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

DEPARTMENT OF ELECTROTECHNOLOGY

INOVAČNÍ TECHNOLOGIE PRO ELEKTROTECHNICKOU VÝROBU

INNOVATIVE TECHNOLOGY FOR ELECTRIC PRODUCTION PROCESESS

BAKALÁŘSKÁ PRÁCE

BACHELOR´S THESIS

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BRNO 2010

BRNO UNIVERSITY OF TECHNOLOGY

Faculty of Electrical Engineering

Department of Microelectronics

Bachelor thesis

bachelor's study field
Microelectronics and Technology

Student: Luboš Lněnička — ***ID:*** 98629
Year of study: 3 — ***Academic year:*** 2009/10

TITLE OF THESIS:

Innovative technology for electrical production process

INSTRUCTION:

Make overview of methods for manufacturing process improvement and describe theories for inventive problems solving with emphasis on electric manufacturing processes.

Solve the model problem concerning real manufacturing problem focused on company with small/middle batch electric production.

REFERENCE:

According of supervision instructions

Assigment deadline: 8.2.2010 — ***Submission deadline:*** 3.6.2010

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Subject Council chairman

Abstract

V Českém jazyce:

Předkládaná práce se zabývá problematikou elektrotechnických výrobních procesů za použití optimalizačních a inovativních metod. Základním zaměřením práce je vytvoření přehledu zakládních optimalizačních metod jako je 6 Sigma, Lean manufacturing, Total Quality management, a dalších. V další fázi půjde o představení a popis inovativní technologie TRIZ. Závěrečnou částí teoretické práce je příkladová studie, ve které je představen postup řešení inovativních návrhů TRIZ, za pomocí alagoritmu ARIZ, k nalezení rešení automatizace meřícího systému.

In English:

This work examines issues associated with improving electrotechnical manufacturing processes, including the application of optimization and innovation methods therein. The general aim is to create an overview of optimization methods such as 6 Sigma, Lean Manufacturing, and Total Quality Management, among others. The next part describes TRIZ, a methodology for inventive problem solving. The final part of this work presents a case study in the use of the algorithm ARIZ, a component of TRIZ used for solving innovative design applications and developing automatic measuring systems.

Klíčová slova:

Optimalize elektrotechnických výrob, Inovatika, 6 Sigma, Lean, TRIZ, Alagoritm ARIZ.

Keywords:

Optimalization electrotechnical manufacturing, Inovative, 6 Sigma, Lean, TRIZ, Alagorithm ARIZ.

Bibliografická citace mé práce:
LNĚNIČKA, L. *Inovační technologie pro elektrotechnickou výrobu.* Brno: Vysoké učení technické v Brně, Fakulta elektrotechniky a komunikačních technologií, 2010. 59 s. Vedoucí bakalářské práce Prof. Leonid Sergeevich Chechurin, St. Petersburg State Polytech.

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V Brně dne 2.6.2010 ....

Acknowledgments:

I would like to express my gratitude to my supervisor Prof. Leonid Sergeevich Chechurin from State Polytechnic University St. Petersburg for all his useful advice, support I needed for writing my thesis, and for the time he spent explaining methodology TRIZ. I would like to thank my supervisor from my home University, to doc. Ing. Ivan Szendiuch, Csc. for his comments and useful advice. Last but not least I would like thank Kryotherm Company for introducing their production of thermoelectric modules and for their case study from their real process.

Contents

Introduction

This work is devoted to basic methods for general, qualitative improvement of electrotechnical manufacturing processes. This introduction focuses specifically on TRIZ, a Theory for Inventive Problem Solving. The ARIZ algorithm, a component of TRIZ, i sused in a demonstration of a real problem facing the local branch of an international company.

The most important question of a manufacturer, not a academic scientist, is how to make things better. That means for technology driven business either how to manufacture a better product or how to improve the existing manufacturing process. There are no formal instruments to answer these quesitons generally. Even when a problem is reduced to a mechanical or electrical problem, conceptual design is still rather art than a methodology. There is only one exception: optimization. Having been studied for several hundrieds yeas, optimizing (or perfecting the known) has many useful instruments and methods. But the design of something new is impossible by optimizing, therefore innovations are always coming «out of blue».

In the present work we are focused on modern methods of improvement of product or process. First, we overview well-know methodologies of production management: quanlitive (like Lean manufacturing) and qualitive (Six Sigma). Then we focus on new method of conceptual design in engineering, a systematic approach to inventive thinking, that becomes popular more and more (it is widely employed by such giants as Samsung, LG, Siemens, General Electric and many others)

The main goal of this work is to understand methods for improving and optimizing eletrotechnical manufacturing, lead process innovation and conceptual design. The understanding is then applied to a real problem facing international company Kryotherm in the production of its thermoelectric modules.

1. Methods of Improvement / Optimizing

1.1 Six sigma

1.1.1 Introduction

Six-Sigma, a highly statistical quality improvement technique born in the manufacturing bays of Motorola in the mid-1980s is often used today at an operational level inside companies to help them cut costs, improve processes, and reduce business cycle times. Its value in this regard is well understood by business leaders today. Less well known, however, is the potential of Six Sigma to serve as a means to help companies formulate and deploy their business strategies, and bring about broad-gauge transformational change to serve, in other words, as a high-order leadership approach, philosophy, and change methodology? Strategic Six Sigma principles and practices can, for example, be used to help companies:

- Specific, integrate, and execute new (or existing) business strategies and missions
- Deal with constantly changing (and increasingly complex) customer requirements
- Accelerate a company's globalization (and global integration) efforts
- Facilitate mergers and acquisitions (Dow's merger with Union Carbide, for example)
- Ensure effective implementation of e-business ventures with their associated strategies and infrastructures
- Accelerate innovation
- Improve marketing channels
- Enhance and condense the corporate learning cycle - the time it takes to translate market intelligence and competitive data into new business practices
- Win the customer care war
- Drive systemic and sustainable culture change
- Improve financial and corporate reporting
- Manage and limit business risk

1.1.2 What SIX-SIGMA exactly is

In the world of Six Sigma companies, the term sigma has come to signify how well a business process, product, or service is meeting the requirements of the marketplace. Six Sigma has come to mean failing to meet a customer requirement only 3.4 times out of a million opportunities.

1.1.3 Strategy of Six-Sigma

In some companies like Dow, Caterpillar, Bombardier, etc. where Strategic Six Sigma has been implemented, that it has radically and quickly improved business performance across a wide family of performance indicators in everything from return on assets to customer satisfaction and timely order fulfillment (external performance metrics). In fact, it became a standard of engineering design at the majority of manufacturers: Samsung, LG, GE… What is interesting and important for TRIZ that TRIZ generally follows the framework and infrastructure of 6 sigma propagation (Six-sigma nowadays has well-established infrastructure at companies: 6-sigma Academies, "Belts", trainers, training plans etc). It needs only to look at the rapidly changing nature of today's business environment and the multiple drivers and pressures that are exerting themselves on the daily operations of companies.

Today, companies are under more pressure than never before and they are focused on emphasis on:

- Develop, implement, and often rapidly revise their business strategy
- Attract, service, and retain customers (often by anticipating their needs before they do)
- Globalize business operations
- Accelerate innovation and research and development (R&D)
- Redesign their sales and marketing channels rapidly
- Manage business risk
- Develop and introduce new products and services faster and more efficiently
- Build national and global brands
- Develop and implement effective supply chains
- Implement transformational change

Six-Sigma tools and concepts provide a means to optimally align all of an organization's components from leaders, culture, and mission and strategy on the one hand, to structure, management practices, systems, work climate, and employee skill sets and behaviors on the other to help a company achieve breakthrough levels of business performance.

Strategic Six Sigma principles and practices have a potentially huge role to play in the planning, building, management, and improvement of quality systems in companies today. Indeed, Strategic Six Sigma principles and practices, if employed effectively, can help a company turn its quality systems into a potent marketplace and competitive weapon.

In essence, it is a whole-enterprise strategy of business process management and improvement based on the following four steps:

1. Measuring business and product/service conformance to customer requirements
2. Creating specific continuous actions to reduce variation in existing business processes that cause failures to conform to customer requirements
3. Creating new innovative products/services and processes to specifically meet customer and market requirements
4. Repeating steps 1 through 3 continuously as necessary for the enterprise to remain viable and sustain shareholder value over the long term Following are the three critical components to Strategic Six Sigma initiatives

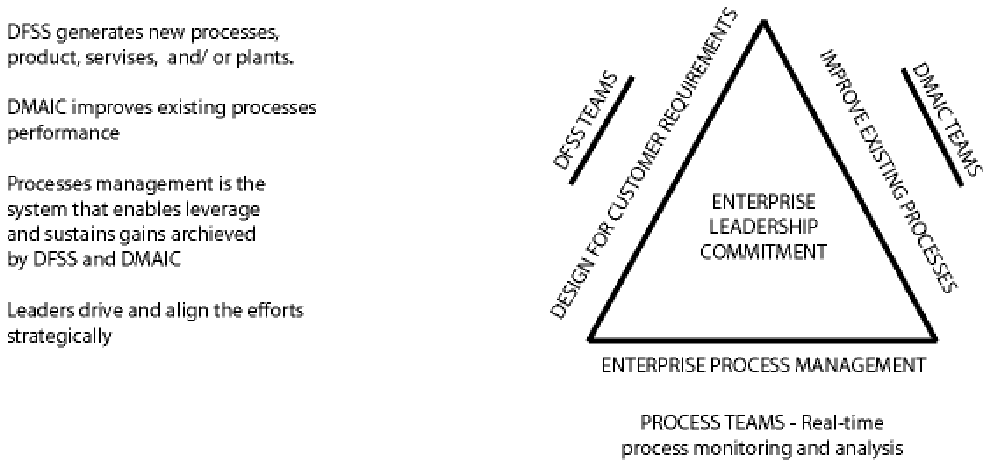

Figure 1 - Elements of Strategic Six-Sigma *(Source: http://www.sixsigma.org)*

1. **Designing processes for customer requirements using Design for Six Sigma (DFSS) teams**.
   DFSS is a robust and systematic improvement methodology that uses specific Six Sigma tools and metrics to design products, services, and processes that meet customer requirements from the outset, and that can be produced and delivered at Six Sigma quality levels.
2. **Improving existing processes using Define, Measure, Analyze, Improve, and Control (DMAIC) improvement teams**.
   DMAIC is a fact-based, closed-loop; problem-solving methodology that ensures continued process/product/ service improvement. It focuses on eliminating unproductive steps, developing and applying new metrics, and using technology to drive improvement.
3. **Enterprise-wide process management using process teams that work in real time to gauge, monitor, and analyze ongoing business and organizational performance.**
   The foundation for sustaining Six Sigma improvements over time is the institutionalizing of business improvement through ongoing process management. Process management requires that a company establish a series of dashboards, metrics, and performance indicators for its core processes through which the top leadership team can continuously monitor and assess performance. These dashboards and metrics typically track and monitor a variety of performance indicators, including: leading indicators, results indicators, customer indicators, and internal indicators.

There's yet another, very sobering reason why Strategic Six Sigma practices are emerging as important to companies today: the escalating prospect of catastrophic business risk.

1.1.4 Conclusion

Six-Sigma is excellent in optimizing the parameters of, say, new product or new technology. It has thoroughly elaborated algorithm of application. But it cannot help to conceive an idea for new product or new technology. [Source: SMITH D.: Strategic Six Sigma – Best practices from the executive]

1.2 Lean manufacturing

1.2.1 Introduction

Improvement method Lean Manufacturing or lean production area terms used to describe a manufacturing, service or operation or industrial. Lean Manufacturing is a unified, comprehensive set of philosophies, rules, guidelines, tools for improving and optimizing discrete processes. Its method, which is working from the perspective of the customer that consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for. Therefore the non value adding "steps" and its associated costs are uncovered by the manufacturing company, thus reducing margins for the manufacturer. Many of the concepts are derived from the Toyota Production systems, which are considered to be the pioneers in several lean manufacturing concepts and principles.

Lean was originally developed for automotive industry sector, but Lean principles and benefits apply to all processes like health care, service, sales & marketing, fast food etc. This is reason, why it is sometimes called "Lean Thinking", rather than the more restrictive title of "Lean Manufacturing".

At the start of the 20th century Manufacturing went through a revolution with the creation of the assembly line to mass produce the Ford model T by Henry Ford. Even then when the lean manufacturing concept was years away, Ford had a focus on reducing time and material waste, increasing quality, and lowering cycle times, in order to achieve a lower cost vehicle which was reflected in the price reduction of the model T year on year. This focus allowed him to reduce costs, even though he paid his workers well, and provide a great value product to the customer.

Nowadays' world more and more organizations are realizing how important quality and customer satisfaction is in order to sustain a competitive business. Market does a pressure to reduce costs and increase efficiencies not only in manufacturing but in different types of industries, such as banking, business and community services. The challenge today is adapting these concepts and technologies to this wide range of industries successfully. The key to success in implementing lean manufacturing principles in any organization is to foster a culture of continuous improvement, lean thinking, and customer satisfaction as the organization's ultimate goal. This shift in culture, if not already present, must come from top management and be embraced by all layers of the organization.

Lean manufacturing is a variation on the theme of efficiency based on optimizing flow; it is a present-day instance of the recurring theme in human history toward increasing efficiency, decreasing waste, and using empirical methods to decide what matters, rather than uncritically accepting pre-existing ideas. As such, it is a part in the larger narrative that also includes such ideas as the folk wisdom of thrift, time and motion study of the Efficiency Movement. Lean manufacturing is often seen as a more refined version of earlier efficiency efforts, building upon the work of earlier leaders such as Taylor or Ford, and learning from their mistakes.

1.2.2 Lean Manufacturing – Principles

Diagnose & eliminate waste everywhere:

- Over Production
- Inventory
- Defects
- Over-processing
- Waiting
- People's talent and motivation
- Motion
- Transportation
-

1.2.3 Lean Manufacturing - Tools and Techniques:

- Single Minute Exchange of dies
- 1-Piece Flow
- Line Optimization
- Synchronous Manufacturing
- KanBan
- Method of Separate, Simplify, Standardize, Sustain 4S
- Total Productive Maintenance
- Value Mapping
- Visual Management

1.2.4 Conclusion

LEAN is a general managerial approach to organize manufacturing in a rational, economic, flexible way. But it is qualities, strategic. There will be no specific recommendations, who changes a specific product of specific technology. [Source: Lombardo.:, FYI: For Your Improvement]

1.3 Quality Function Deployment

1.3.1 Introduction

Quality Function Deployment (or QFD) was originally developed in Japan in 1966 by Dr. Yoji Akao like method to transform user demands into design quality to deploy the functions forming

quality. This methods for achieving deploys in the design quality into subsystems and components parts, and ultimately to specific elements of the manufacturing process.
Quality Function Deployment (QFD) is a means of translating customer requirements into appropriate technical requirements for each stage of product or service development and production. QFD is a tool for helping planners, who are focused on characteristics involving new products; edit existing products or service from the view points of market segments, technology-development, or company needs.
Quality Function Deployment (QFD) is a way of making the 'voice of the customer' heard throughout an organization. It is a systematic process for capturing customer requirements and translating these into requirements that must be met throughout the 'supply chain'. QFD is particularly valuable when design trade-offs are necessary to achieve the best overall solution. The main 'bottom line' benefits of using QFD include greater likelihood of product success in the marketplace due to the precise targeting of key customer requirements, reduced overall cost due to reducing design changes, reduced product cost by eliminating redundant features and over-design. The article also shows a QFD chart to make the concept much clearer. Hence QFD is used to establish product and component characteristics which need to be controlled in order for the outputs to meet customer requirements.

1.3.2 Processes of QFD

The idea of QFD is timing, performance evaluation, and resource commitment. And the four phases of QFD are:

1. Product concept planning. It starts with customers and market research with leads to product plans, ideas, sketches, concept models, and marketing plans.
2. Product development and specification. It would lead to the development to prototypes and tests.
3. Manufacturing processes and production tools. They are designed based on the product and component specification
4. Production of product. It starts after the pilot have been resolved

After the products have been marketed, the customer’s voice is taken again.

1.3.3 Benefits of QFD

QFD has been evolved by product development people in response to the major problems in the traditional processes, which were:

1. Disregard the voice of customer
2. Disregard the competition
3. Concentration on each specification in isolation
4. Low expectations
5. Little input from design and production people into product planning
6. Divergent interpretation of the specifications
7. Lack of structure
8. Lost information
9. Weak commitment to previous decisions

1.3.4 Conclusion

Quality function deployment is ideal method of translating customer requirements into appropriate technical requirements for all stages production or service. [Source: Lombardo.:, FYI: For Your Improvement]

1.4 Total Quality Management

1.4.1 Introduction

Total Quality Management, also known as TQM, is a management concept created by W. Edwards Deming. The basis of TQM is to decrease the errors produced during the manufacturing or service process to ratio of 1 per 1 million units produced, increase customer satisfaction, streamline supply chain management, aim for modernization of equipment and ensure workers have the highest level of training. The application of TQM can vary tremendously from business to business, even across the same industry.

The core of TQM is the customer-supplier interfaces, It means externally and internally, and at each interface lie a number of processes. This core must be surrounded by commitment to quality, communication of the quality message, and recognition of the need to change the culture of the organization to create total quality. These are the foundations of TQM, and they are supported by the key management functions of people, processes and systems in the organization. This section discusses each of these elements that, together, can make a total quality organization. Other sections explain people, processes and systems in greater detail, all having the essential themes of commitment, culture and communication running through them.

A frequently used definition of quality is “Delighting the customer by fully meeting their needs and expectations”. These may include performance, appearance, availability, delivery, reliability, maintainability, cost effectiveness and price. It is, therefore, imperative that the organization knows what these needs and expectations are. In addition, having identified them, the organization must understand them, and measure its own ability to meet them. Quality starts with market research – to establish the true requirements for the product or service and the true needs of the customers. However, for an organization to be really effective, quality must span all functions, all people, all departments and all activities and be a common language for improvement. The cooperation of everyone at every interface is necessary to achieve a total quality organization, in the same way that the Japanese achieve this with company wide quality control.

1.4.2 Customers versus suppliers

There are in all departments, every office, every home, a series of customers, suppliers and customer supplier interfaces. These are “the quality chains”, and they can be broken at any point by one person or one piece of equipment not meeting the requirements of the customer, internal or external. The failure usually finds its way to the interface between the organization and its external customer, or in the worst case, actually to the external customer.

Failure to meet the requirements in any part of a quality chain has a way of multiplying, and failure in one part of the system creates problems elsewhere, leading to yet more failure and problems, and so the situation is exacerbated. The ability to meet customers' (external and internal) requirements is vital. To achieve quality throughout an organization, every person in the quality chain must be trained and must be informed about customers and Suppliers. As well he should know who are own customers, and knows their needs and expectations. Same situation is with suppliers; all persons in quality chain must know internal suppliers and the real needs and expectation. The ideal situation is an open partnership style relationship, where both parties share and benefit.

1.4.3 TQM in practices

To be able to become a total quality organization, some of the bad practices must be realised and eliminated following things:

• Leaders not giving clear direction
• Misunderstanding, or ignoring competitive positioning
• Each department working only for itself
• Trying to control people through systems
• Confusing quality with grade
• Accepting that a level of defects or errors is inevitable
• Firefighting, reactive behavior

1.4.4 The basic components of TQM

TQM is an approach to improving the competitiveness, effectiveness and flexibility of an organization for the benefit of all stakeholders. It is a way of planning, organizing and understanding each activity, and of removing all the wasted effort and energy that is routinely spent in organizations. It ensures the leaders adopt a strategic overview of quality and focus on prevention not detection of problems.

Whilst it must involve everyone, to be successful, it must start at the top with the leaders of the organization. All senior managers must demonstrate their seriousness and commitment to quality, and middle managers must, as well as demonstrating their commitment, ensure they communicate the principles, strategies and benefits to the people for whom they have responsibility. Only then will the right attitudes spread throughout the organization.

A fundamental requirement is a sound quality policy, supported by plans and facilities to implement it.

Leaders must take responsibility for preparing, reviewing and monitoring the policy, plus take part in regular improvements of it and ensure it is understood at all levels of the organization. Effective leadership starts with the development of a mission statement, followed by a strategy, which is translated into action plans down through the organization. These, combined with a TQM approach, should result in a quality organization, with satisfied customers and good business results. The 5 requirements for effective leadership are:

- Developing and publishing corporate beliefs, values and objectives, often as a mission statement
- Personal involvement and acting as role models for a culture of total quality
- Developing clear and effective strategies and supporting plans for achieving the mission and objectives
- Reviewing and improving the management system
- Communicating, motivating and supporting people and encouraging effective employee participation.

The task of implementing TQM can be daunting. The following is a list of points that leaders should consider; they are a distillation of the various beliefs of some of the quality gurus:

- The organization needs a long-term commitment to continuous improvement.
- Adopt the philosophy of zero errors/defects to change the culture to right first time
- Train people to understand the customer/supplier relationships
- Do not buy products or services on price alone – look at the total cost
- Recognize that improvement of the systems must be managed
- Adopt modern methods of supervising and training – eliminate fear
- Eliminate barriers between departments by managing the process – improve communications and teamwork
- Eliminate goals without methods, standards based only on numbers, barriers to pride of workmanship and fiction – get facts by studying processes
- Constantly educate and retrain – develop experts in the organization
- Develop a systematic approach to manage the implementation of TQM

1.4.5 Conclusion

Total Quality Management is very similar with Six- Sigma. It is usually associated with the development, deployment, and maintenance of organizational systems that are required for various business processes TQM tries to improve quality by ensuring conformance to internal requirements, while Six Sigma focuses on improving quality by reducing the number of defects [Source: Lombardo.:, FYI: For Your Improvement]

2. Problems of manufacturing process improvement

Innovation is a new way of doing things that is commercialized. Innovation is the profitable implementation of strategic creativity. John Kao at the recent SPIE Photonics Innovation Summit in San Francisco said that: ‘Innovation is creativity for a purpose that provides value.’ If one believes innovation is the conversion of knowledge into money, it becomes apparent that customers are the ultimate judge. If your technology roadmap doesn’t point to articulated customer needs, ask: ‘Why are we doing this?’

Not all discoveries or promising inventions turn into successful products. In fact, very few do. The process of innovation includes discarded projects, missed opportunities and high levels of uncertainty. This is more a game of poker than chess. It costs money to reduce uncertainty and money is tighter than ever. The best way to improve the odds is to connect more deeply with your target customers – because they alone determine whether you have an innovation. Companies with the best understanding of need combined with the ability to produce more technical possibilities have a strategic advantage. Being able to connect possibilities with needs is the essence of innovation. One cannot successfully commercialize technology without understanding the market, including specific applications, target customers and alternative solutions. Methods for basic research “Bravo” and a robust technology pipeline. Yet, few companies can afford an internally focused ‘if we build it they will come’ strategy. Developing a common understanding of real problems to solve and a sense of urgency about delivery to the customer are critical management issues.

Getting close to the market helps you better understand needs and search for changes to exploit. Peter Drucker tells us that most innovation opportunities emerge from seeing surprises, incongruities or changes. Relatively few innovations come from an inventor’s ‘bright idea’ or even from new scientific knowledge. This means that the innovation process depends primarily on people looking outward. The most cost-effective way to connect with the market is to go where a critical mass of intelligent people from multiple disciplines, many organizations and different viewpoints are already gathering. SPIE Photonics West is such a place – a breeding ground for innovation, where you can learn new possibilities, talk with customers and get a better sense of market needs, and see for yourself what is changing. Innovation happens best when people stretch the boundaries of their knowledge, or cross boundaries and share time in an environment where ideas can flow freely among scientists, engineers, entrepreneurs and executives.

3. TRIZ

3.1 Introduction

″The theory of solving inventive problems" or "The theory of inventive problem solving"., known like TRIZ. TRIZ is acronym for Russian definition „**T**eoriya **R**esheniya **I**zobretatelskikh **Z**adatch”

Nowadays, We use TRIZ like a methodology, tool set, knowledge base, and model-based technology for generating innovative ideas and solutions for problem solving. TRIZ’s utilities help us to define problem, make his formulation, system analysis, failure analysis, and patterns of system evolution. TRIZ, in contrast to techniques such as brainstorming , aims to create an algorithmic approach to the invention of new systems, and the refinement of old systems.

Some TRIZ is in the public domain. Some TRIZ resides in knowledge bases held by commercial consulting organizations. A complete and open TRIZ development process is not yet evident. Various camps vie for control of TRIZ and interpretation of its findings and applications.

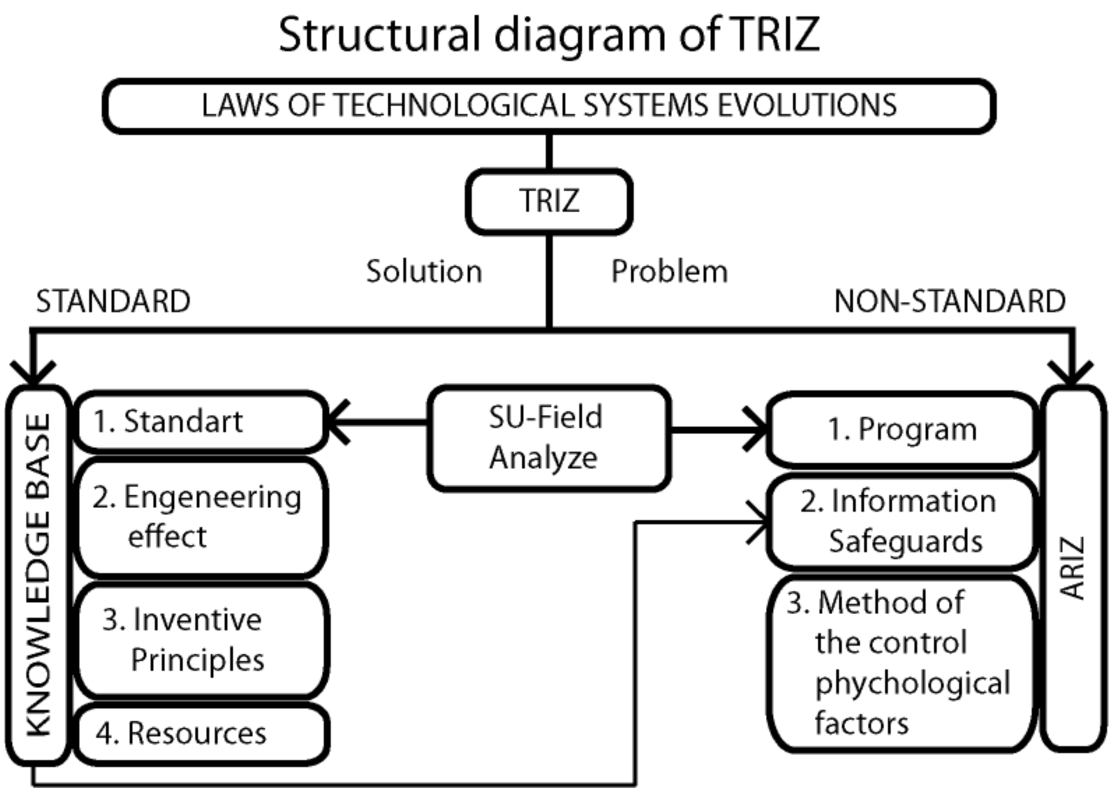

Figure 2 - Structural diagram of TRIZ [source: http://wikipedia.org]

3.2 History of TRIZ

This methodology of solving problems was developed in Soviet Union. The first idea about systematic approach to inventive thinking was expressed in 1946 by a Soviet patent agent Genrich Altshuller and his colleague. It has been evolving ever since. The first publication about the subject was published in 1956.

In 1946, at the age of 20, Altshuller developed his first mature invention - a method for escaping from an immobilized submarine without diving gear. In the late 1940s he has worked in the "Inventions Inspection" Altshuller's job was to inspect invention proposals, help document them, and help others to invent. By 1969 he reviewed about 40,000 patent abstracts in order to find out in what way the innovation had taken place. He eventually developed 40 Principles of Invention, several Laws of Technical Systems Evolution, the concepts of technical and physical contradictions that creative inventions resolve, the concept of Ideality of a system and numerous other theoretical and practical approaches; together, this extensive work represents a unique contribution to the development of creativity and inventive problem-solving.
The tools developed under Altshuller's leadership were born approach for successful thinking in engineering problems of different background. In contrast with trial and error, brain storming of Taguchi methods if is based on technical system development philosophy, system theory and 1,000,000 patent analysis. It gives to an engineer a knowledge-based method to generate new ideas.

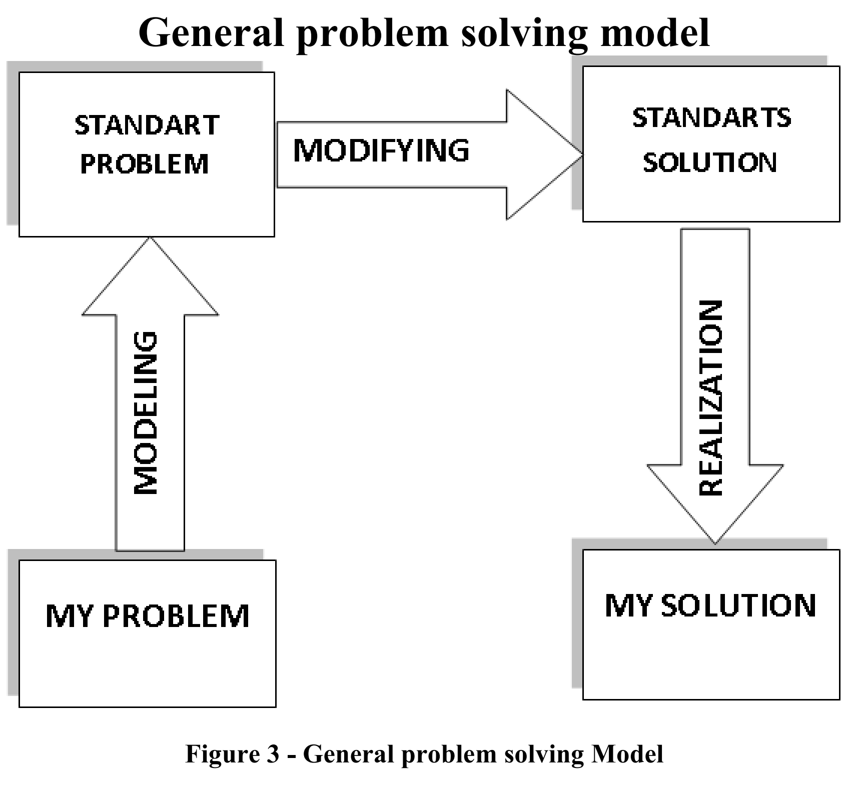

Figure 3 - General problem solving Model

3.3 Real problem - identifying a problem

According to G. Altshuller, process of invention could be more systematic and based on certain steps. He also gave a devinition of invention that was different to one known form patent industry: any invention resolves certain contradiction. Altshuller analysed 40.000+ patents and distilled a collection of “best engineering practices” he called Principles of resolving contradictions. To inventive, what he argued, one must identify the contradictions in the problem and aplly corresponding principles of its resolving. He also introduced several other tools for systematic thinking to invent.

His results are being applied to solve creative invention problems not just within all branches of engineering, but within many other technical and non-technical fields as well.

The effectiveness of TRIZ is in dispute in many Engineering circles. Claims by some inventors that they arrived at their inventions with the help of TRIZ cannot be independently verified. Very often managers try to introduce TRIZ into their organizations in order to not be blamed for failures means.

TRIZ is also sold to people outside of engineering disciplines as a way to 'produce' creativity in many field of human activity without any grounds for that and ignoring the fact that traditionally TRIZ has grown up in the domain of engineering.

3.4 Modeling

As in any theory, the first step is a transition from real problem to its formal image using specific language of the theory. Thus, we use differential equations in mechanical and physical problems or atomic structure construction for material modeling in chemistry. In TRIZ they also use certain formal language for describing a technical system or a problem. There are three basic modeling techniques: by contradictions, by representing as so called Standard Technical System, by Substance-Field Model.

3.4.1 Contradiction

Contradiction is a situation when two, mutually excluding requirements are exposed to one part or different parts of one technical system

Administrative contradiction:

Administrative contradiction is a sort of primary situation. It is characterized by a quantitative requirement. Administrative contradiction initiates innovation process, but there are not very specific how to do this process of innovation.

Technical contradiction:

Technical contradiction in technical system is a conflict between two parameters. (For instance: "weight-strength", or "accuracy-productivity").When we need to analyze the administrative problem, we must select and set up a conflicting parts or conflicting system properties. Because one parameter in conflict pairs depends on second parameter, so when one of them is improved, second one could be impaired.

If you perform more careful analysis, if you analyze the causes of these technical contradictions you could go as deep as Physical contradiction.

Physical contradiction:

Physical contradiction is characterized by a situation when two, mutually excluding physical requirements, are exposed to one part of system.

A very important step in problem analysis is the formulation of contradiction. In fact, most of project analysis time is spent to build it up. When we have formulated a contradiction, we should compromise it, In inventive process we fight to eliminate the contradiction.

Contradictions are unlikely seen in administrational problem setup. Particularly, in measurements problems and in problems of functionality improvement.

TRIZ provides a technique to work out a conceptual idea at the level of administrative contradiction when a contradiction is "hidden". This technique is called Substance-Field Analysis. However, having performed a certain analysis, we could figure out a technical contradiction. In the first example it might be put as productivity/equipment complexity. In the second example we may observe it as transportation difficulty/functionality.

Finally, when we approach a physical contradiction level, TRIZ suggests standards to resolve them as well. "See TRIZ Standard technique for physical contradiction elimination".

Examples of contradictions:

<u>The administrative contradiction:</u>

It is necessary to detect the number of small < 0.3 micrometers particles in a liquid with very high optical purity. Particles reflect light very badly even if we use a laser.

<u>The technical contradiction</u>

If the particles are very small the liquid stays optical pure, but the particles are invisible. **XOR** if the particles are big they are detectable, but the liquid is not pure.

<u>The physical contradiction:</u>

The particles has to increase their sizes to be viewed **ANDNOT** to increase the sizes to keep the optical purity of the liquid.

The most important achievement of TRIZ was the finding that although the number of various technical systems could be infinite, the number of contradictions are limited. For example, a contradiction between "Speed" and "Stability" could be found in mechanical problem of, say, rapidly rotating rotor and in chemistry for, say, a poorly controlled chemical reaction.

3.4.2 Definition of Standard a Technical System in TRIZ

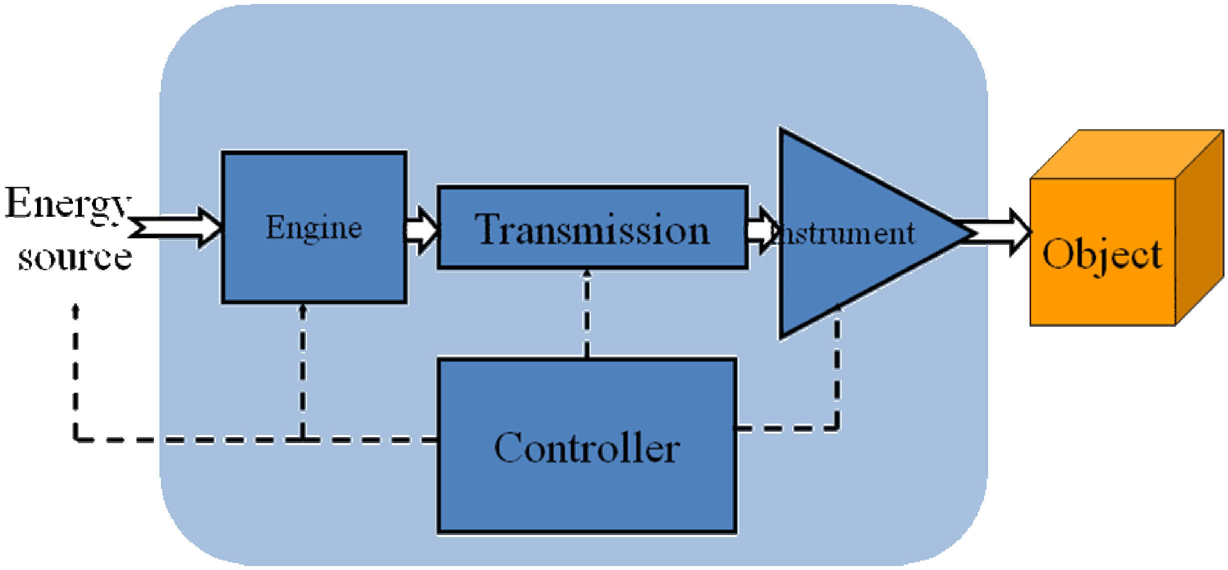

Figure 4 - Definition of a Technical System in TRIZ [source: http://ww.triz-journal.com]

One of main parts of TRIZ analyzes is modeling a technical system or situation by a kind of primer elements. It is useful for getting rid of thinking inertia caused by linguistic or professional "programming". TRIZ modeling represents a technical system as a combination of "faceless" elements that helps to focus on its function rather than "image".

The most general way of modeling is associated with energy flow. Once we represented out technical system this way, TRIZ provides simple recommendations to improve it. E.g. transmission is the first candidate to be reduced. The most of attention should be given to the pair Tool-Object etc.

3.4.3 Standard Technical System – Definition

Basic definitions of technical systems

Although inventive problem solving theory has been successfully applied in different parts of human activities (even in advertising and election campaigns), today we focus on technical problems, problems related to technical systems. Let us spend some time understanding what the technical system is.

1st Definition
Technical System is defined if we describe its parts, links between them and its **Primary Function**

Another definition of Technical system follows from more general system definition: technical system is such an interconnection of units and elements that its function is more then a sum of functions of its parts.

2nd definition

Primary Function is one general process for which TS is comprised

3rd definition

Object is something that is supposed to be treated by the TS (produced, moved, protected…). **Product** is the Object, that has been treated by TS.

To exist any Technical system should consist at least of 4 parts: *engine*, *transmission*, *tool* and *control system*.

4th definition

Engine is a part of system that provides required sort of **energy**.

5th definition

Transmission is a part or TS that transfers energy to the **Tool**.

6th definition

Tool is an element of technical system that interacts with the **Object** directly. (heat, but not heater; glass particles but not electron gun…)

3.4.4 Substance-field analysis

One more technique that is frequently used by inventors involves the analysis of substances and fields that are currently not being used and that can be found within the system or nearby. TRIZ uses non-standard definitions for substances and fields. Altshuller developed methods to analyze resources, several of his invention principles involve the use of different substances and fields that help resolve contradictions and increase ideality of a technical system.

SubField Analysis is divided to following classes:

Class 1: - Synthetic of SuFields

Class 2- Evolution of SuField systems

Class 3 – Transition to a higher level system and to micro-level

Class 4 – Standards for detecting and measurement

Class 5 – Standards on application of the standards

3.4.5 Conclusion:

There are three methods to model real engineering system or process in TRIZ: Engineering and Physical Contradictions, Standard Engineering System, Substance-Field Model.

3.5 Modifying

As in any theory, the modeling itself does not help much to improve the system. Any theory uses specific formalism in order to modify the model. In differential equations we have formal rules of changing them or optimizing them, in chemistry we have rules of reactions in order to modify the substance. In TRIZ once we have the model of a real system by a contradiction, Standard Technical System or a SubField we may use methods of modifying our model in order to make it better. These methods are: Altshuller Matrix, Standards for Physical Contradiction Resolving, Concept or Ideal Final Result. Trends of Engineering System Evolution are helpful too in order to find a concept for disruptive improvement**.**

3.5.1 Best Engineering Practice

Easy way how to find solution for problems is in previously well-solved problems. Altshuller extracted from over 1,500,000 world-wide patents these 39 standard technical characteristics that cause conflict. These are called the 39 Engineering Parameters shown in Table 1. Find the contradicting engineering principles. First find the principle that needs to be changed. Then find the principle that is an undesirable secondary effect. State the standard technical conflict.

3.5.2 Altshuller's Matrix

The Matrix of Altshuller is a system how to select an appropriate principle (principles) in order to eliminate our contradiction. It we select the chosen improving feature among matrix columns and the chosen degrading feature - see point ”**Error! Reference source not found.** properties - among matrix rows, the matrix entity provides a number(s) of principles we should apply. It should be pointed out that we fail to find “Cost” feature among the 39 Standard properties. This value is to be expressed in technical terms. E.g., if the material is expensive then choose “loss of substance” etc.

Generally, the Matrix provides more than 1 principle. The latter could mean one of the following.

a) There are several principles that could be used to resolve our contradiction. However, the most appropriate is first listed.
b) Our solution could be a combination of the listed principles.

There are some empty slots in the Matrix. It means that either this conflict could not happen in nature of there are principles (physical effects) to come. The same situation is with empty slots of periodic table.

Conflict Properties	1. Weight	2. Speed	…	12. Shape	…	39. Productivity
1. Weight						
2. Speed						
…..						
12. Shape						
….						
39. Productivity						

Figure 5 - Altshuller's Matrix [Source: http://wikipedia.org]

39 Standard properties

Table 1 – 39 Standard properties [http://wikipedia.org]

1 Weight of movable object	21. Power
2. Weight of fixed object	22. Waste of energy
3. Length of movable object	23. Loss of substance
4. Length of fixed object	24. Loss of information
5. Area of movable object	25. Waste of time
6. Area of fixed object	26. Quantity of substance
7. Volume of movable object	27. Reliability
8. Volume of fixed object	28. Measurement accuracy
9. Speed	29. Manufacturing precision
10. Force	30. Harmful action at object
11. Stress, pressure	31. Harmful effect caused by the object
12. Shape	32. Ease of manufacture
13. Object's composition stability	33. Ease of operation
14. Strength	34. Ease of repair
15. Duration of moving object's operation	35. Adaptation
16. Duration of fixed object's operation	36. Device complexity
17. Temperature	37. Measurement or test complexity
18. Illumination	38. Degree of automation
19. Energy expense of movable object	39. Productivity
20. Energy expense of fixed object	

40 Inventive principles

Table 2 – 40 Inventive principles [http://wikipedia.org]

1 Segmentation	21. Rushing through
2. Extraction	22. Convert harm into benefit
3. Local quality	23. Feedback
4. Asymmetry	24. Mediator
5. Combining	25. Self-service
6. Universality	26. Copying
7. Nesting	27. Inexpensive, short-lived object for expensive, durable one
8. Counterweight	28. Replacement of a mechanical system
9. Prior counter-action	29. Pneumatic or hydraulic construction
10. Prior action	30. Flexible membranes or thin film
11. Cushion in advance	31. Use of porous material
12. Equipotentiality	32. Changing the color
13. Inversion	33. Homogeneity
14. Spheroidality	34. Rejecting and regenerating parts
15. Dynamicity	35. Transformation of the physical and chemical states of an object
16. Partial or overdone action	36. Phase transformation
17. Moving to a new dimension	37. Thermal expansion
18. Mechanical vibration	38. Use strong oxidizers
19. Periodic action	39. Inert environment
20. Continuity of a useful action	40. Composite materials

Examples of using 40 Inventive principles in Microelectronic:

Principle 2. Taking out/Separation/Removal/Extraction/Segregation

Separate an interfering part or property from an object, or single out the only necessary part (or property) of an object.

- ***Clean rooms.***
- ***Isolation of Copper areas at wafer fab.***
- ***Separation of wafers from people.***
- ***Impurities segregation at Si crystal growth (CZ process).***
- ***Polarized light microscopy.***
- ***Electrical and visual screening.***

Principle 4. Asymmetry/Symmetry change

A. *Change the shape of an object from symmetrical to asymmetrical.*
- ***SEMI standard for Si wafers crystallographic orientation marking:***
- ***P-n junction asymmetry.***

B. *Change the shape or properties of an object to suit external asymmetries.*
   - ***Anisotropic plasma etching.***

C. *If an object is asymmetrical, increase its degree of asymmetry.*
   - ***Increasing features aspect ratio.***

Principle 13. Inversion/Reverse/"The other way round"

A. *Invert the action(s) used to solve the problem (e.g. instead of cooling an object, heat it).*
   - ***Dark field microscopy.***
   - ***Positive photoresist vs negative photoresist.***
   - ***Substractive vs additive lithography.***

B. *Make movable parts (or the external environment) fixed, and fixed parts movable.*
   - ***Electron motion interpretation by 'hole' motion.***

C. *Turn the object (or process) 'upside down'.*
   - ***MOS structure inversion.***
   - ***Lift-off lithography.***
   - ***Stress-Free Polishing (SFP) as reverse process to Electrochemical Deposition (ECD).***

[Source: http://www.triz-journal.com]

3.5.3 Separation principles

TRIZ problem solving methods are separated four very powerful tools known as separation principles. For physical problems or organizational problems, they can be quickly applied to generate new ideas. There are four of these principles: (1) separation in time, (2) space, (3) between parts and the whole, and (4) separation upon condition.
If we apply these principles, in turn, to the conflict of ongoing business vs. innovation and new business, we might come up with the following ideas
1. Separation in time:
Set aside a specific time for discussion of only new, unrelated to current business activities.
2. Separation in space:
Set aside a specific room where only new business ideas can be discussed.
3. Separation between parts and the whole:
Set up a totally separate goup to pursue new activities with reports to senior manager with direct accountability for generating "new to the company" business
4. Separation upon condition:
Hold a simulated exercise triggered by a real or imagined condition (i.e. the issuance of a new patent, the announcement of a competitive merger, etc.). Use this situation, real or imagined, to generate ideas relating to what the organization might do.

3.5.4 Ideal Final Result

Ideal Final Result is the best solution, which is possible to realize for the problem situation, regardless of the resources or constraints of the original problem. IFR is one of the basics terms in TRIZ, a problem solving methodology.

If we have well-defined IFR, that helps a problem solver to overcome psychological inertia and reach breakthrough solutions by thinking about the solution in terms of functions, not the intervening problems or needed resources. It focuses on functions needed, not the current process or equipment.

The clear defined ideal final results is to the goal of improvement and eliminate rework (solve the right problem initially).

3.6 Realization

Realization is part where we implement ideal solution to real system. It is not very easy because if we find ideal solution, we do not admit all negative effect which can impress system in real situation. One way how to transfer ideal solution to real system is to make software simulation. Software TechOptimizer can help us to implement it.

3.6.1 TechOptimizer

TechOptimizer is software developed for implementing ideals solution to real systems. It is fueled by a technical knowledge base, commonly referred to as the Effects Module, which contains over 7500 scientific and engineering effects and examples in all areas of engineering, physics and chemistry. Now, with new context-sensitive help mentors and wizards to provide step-by-step guidance, TechOptimizer is an even simpler, more effective tool. The new version features more than 100 enhancements, which were made based on customer feedback as well as internal research to make TechOptimizer the best-of-breed tool.

3.6.2 Sematic Search Engine

A semantics search engines help us to search results in context. SSE can automatically identify the concepts structuring the texts. For example, if you search for “elevator” a semantic search engine might retrieve documents containing the words “lift”, “transport” and “hoist”, even if the word “elevator” is not found in the source document.

Disambiguation is an important part of this process, both of the queries and of the content on the web. What this means is that the search engine — through natural language processing — will know whether you are looking for a cloths or a big cat when you search for “Puma”.

The five search engines use semantic analysis to sift through and present data. But, they do not do this in the same way and present five different products.

List of the top 5 semantic search engines:

1. Hakia is a general purpose semantic search engine, as opposed to e.g. Powerset and Cognition that search structured corpora (text) like Wikipedia

2. SenseBot is a web search engine that summarizes search results into one concise digest on the topic of your query. The search engine attempts to understand what the result pages are about. For this purpose it uses text mining to analyze Web pages and identify their key semantic concepts.

3. Powerseet is at present not a regular web search engine. It works best on smaller, relatively structured corpora.

4. DeepDyve DeepDyve is a powerful, professional research tool available for free for the general public.

5. Cognition has a search business based on a semantic map. It is developed for more than 24 years, and now it would be the most comprehensive and complete map of the English language available today. It is used in support of business analytics, machine translation, document search, context search, and much more.

4. Trends of Technical system evolution

Trends of evolution are another powerful technique in TRIZ. Trends are used to predict the future characteristics of the products in the process of product evolution.

This concept is based on the fact that all products, process or technical systems evolve over time. They go through an evolution from infancy through old age. Evolution is desirable as higher evolution means better product. The analysis says there are certain patterns of evolution which repeats in every product or system. TRIZ claims that if we can apply these trends or patterns properly we can predict the future stages of a product or system.

The number of patterns in the evolution are not fixed or decided, they are still under development by different TRIZ researchers. You may add a couple of patterns for your purpose as suitable, but the underlying concept is the same. The patterns are derived from the life cycles of the products. The life cycles are represented by S-curves. The four main stages of S-curve are infancy, rapid growth, maturity and old age.

Thus, not only the Inventive Principles are used repeatedly, but the patterns of evolution are also used repeatedly. This means, we can apply these patterns or trends (generic) on any product (specific) to predict the future inventions. In another sense, this can be applied on any patent application to expand on the claims and improve on the invention.

4.1 S-Curve of technical system evolution

S-Curves are a phenomenon showing the typical path of product performance in relation to investment in R&D. At first, performance rises fast and from then on, once a decline in the slope occurs the productivity is unlikely to increase much by heavy R&D expenses. More likely, a technological discontinuity will occur where an innovative technology is introduced and rapidly creates massive gains in productivity. At the start of the curve, a significant effort is needed to get an achievement, but once this basic learning has been done, productivity can advance significantly with little marginal effort. After a few years further advances get more and more fractional. As technology generations change, few incumbents survive because of a lack of adapting to the new technology.

Usage of the S-Curve:

- Technology life cycle assessment
- Industry maturity
- Assignment of necessity of strategic refocusing

Various parts (subsystems) of a technical system evolve at non-uniform rates. The more complex is the system, the more non-uniform it is. It leads to system conflicts or contradictions. And, consequently, it makes a demand for R&D and inventive process.

Example: Ship brakes.
Analysts say that a general system (technical, biological etc.) evolution picture looks on Figure no. 6.

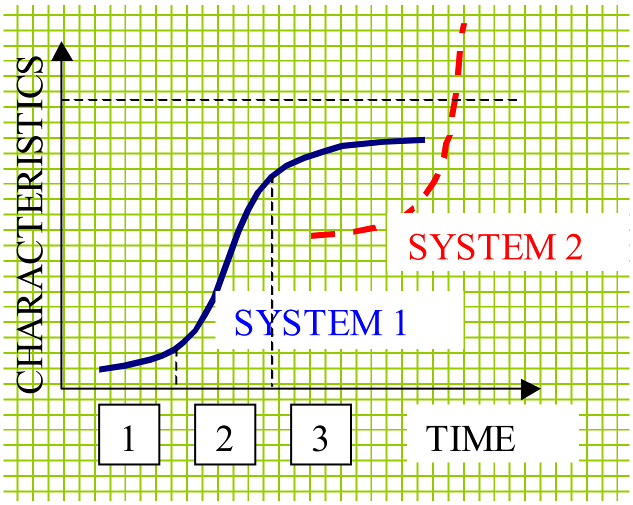

Figure 6 - Technical system quality development

[Source: Chechurin L. S.: Intensive course SE]

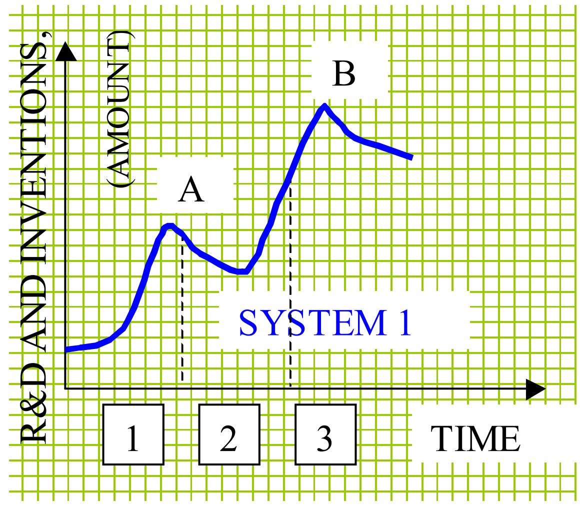

Figure 7 - Number of inventions

[Source: Chechurin L. S.: Intensive course SE]

1st Phase – is system study and development.
2nd Phase - is mass production. The system is developed promptly. “Bigger size”, “Higher speed”, “Lower price”
3rd Phase – is maintenance, saturation. System is still in use, but it almost achieved physical limits of existence. It needs big efforts for small improvements. It is time to study and develop a qualitatively new system.

Characteristic improvement follows system change, when a new idea, an invention or new R&D studies give such an opportunity. In all cases, one needs to introduce something novel, to make a change, in other words, and to make an innovation.
We will name as innovation any kind of changes of system that have not happened to it before.
This S-curve could reflect a system part development as well as a system as a whole. In the latter case, the curve, being magnified, could be observed as number of small S-curves corresponding to system part improvement.

There is a horizontal line a system reaches asymptotically. It reflects system potential, restricted by nature. E.g. you can hardly expect a bicycle driving 100 km/hour. However, if the quality is expressed in speed terms, then a transfer to another conception should be done.

Any improvement of a technical system happens due to certain progress in research and development (R&D) and due to inventions. It is interesting to see average amount of R&D and inventions corresponding to the mentioned phases (see on figure 7.).

The pick A corresponds to a launch of mass production and pick B corresponds to a situation when system is getting old but needs to be maintained or improved. It should not be misunderstood from the figure that we need more inventions by the end of product life cycle, since there are different levels of inventions and different depth of R&D work. We should put here a classification, adopted in TRIZ. They classify all inventions, according to a contribution (impact) it has.

- 1st grade (the lowest) corresponds to inventions dealing with slight changes, upgrading, and modification of one certain system part (E.G. A modification of gas balloon cap by additional reinforcement groove).
- 2nd grade invention involves at least choice of a part to improve (E.G. A pier pillar wave cleaner), solution is found within the same problem branch (tension type SM from formed type one, etc)
- 3rd grade invention is characterized by full change of one part of system. Solution is found within the same engineering field (mechanical problem is solved by mechanical methods etc).
- 4th grade inventions results in a new system. Problem solution is found by methods of different engineering fields (e.g. PDP instead of CRT etc)
- 5th grade invention has a breakthrough result. It could be compared with a scientific discovery, opening a new challenge for technical development. (Laser, phone, airplane)

We think that R&D work could be classified the same way. Thus, the level of inventions or depth of R&D work is presented in **Error! Reference source not found.**8.

The figure tells us that breakthrough inventions and fundamental researches give a qualitative move to a new system or new product or new technology.

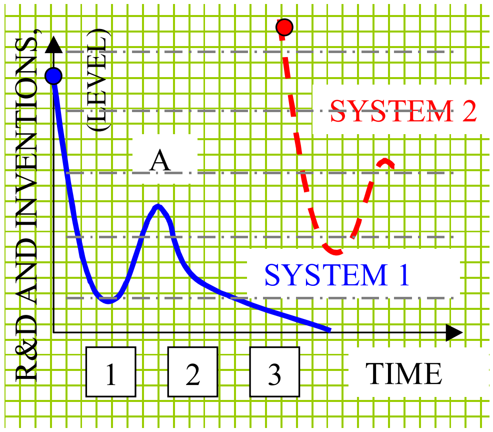

Figure 8 - Level of R&D and invention process

[Source: Chechurin L. S.: Intensive course SE]

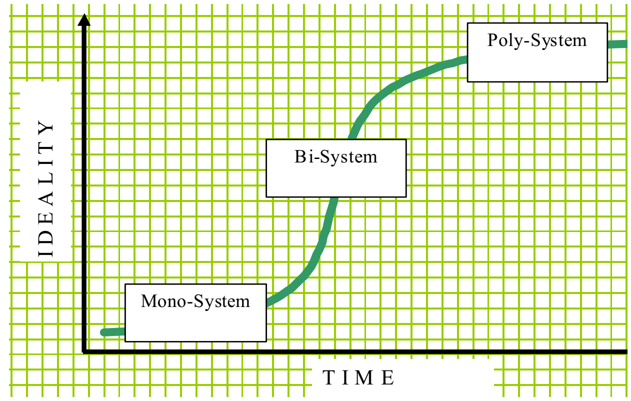

Figure 9 - Mono- Bi- Poly- Evolution

[Source: Chechurin L. S.: Intensive course SE]

4.2 The Law of Ideality Increase

One of the insights by Altshuller is that all technical systems (or artifact systems) have a number of trends of evolution, which are common across the fields and eras.
Over a dozen of such trends of system's evolution have been recognized. It guides us to think along these courses of trends and to find futuristic technical innovations right now.
TRIZ teaches us these common trends in technical system evolution at a highly abstract level, together with illustrations of concrete practical examples.

There is one fundamental law in the theory of TRIZ.

Definition 1.:

Ideality of Technical System is a quotient of the sum of the system's useful effects, U_i, divided by the sum of its harmful effects, H_j :

$$<Ideality> = I = \frac{\sum U_i}{\sum H_i} \quad . (1)$$

Useful effects include all the valuable results of the system's functioning. Harmful effects include undesired inputs such as cost, footprint, energy consumed, pollution, danger, etc.

Then, The Law of Ideality Increase takes the form:

Technical systems evolve toward increasing degree of ideality

The ideal state is one where there are only benefits and no harmful effects. It is to this state that product systems will evolve. From a design point of view, engineers must continue to pursue greater benefits and reduce cost of labor, materials, energy, and harmful side effects. Normally, if the benefit improving results in increased harmful effects, a trade-off is made, but the Law of Ideality drives designs to eliminate or solve any trade-offs or design contradictions. The ideal final result will eventually be a product where the beneficial function exists but the machine itself does not. The evolution of the mechanical spring-driven watch into the electronic quartz crystal watch is an example of moving towards ideality.

Ideality is a good evaluation parameter for new design estimation.
Good news for us is that no commercially available technical system evolution follows the Ideality Increase Law. In contrast to any physical law, the Technical system development laws could be violated.

4.3 The trend of Functionality evolution

Following the ideality increase Law, the functionality of system increases. Systems provide more comfort by providing more functions. It results in introduction of new subsystems, or new parts of our technical system. It is interesting to analyze regularity in new part appearance.

A technical system could evolve in a general direction from mono-system to bi- or poly-system.

A single object is a mono-system. Most of technical systems are originated as mono-systems.

You may consider a pencil as an example.
Let us observe what happens to the pencil as the time goes. Some parts of it are improved, the graphite stem becomes softer or harder, stem coating becomes more elegant or easy-to-peal etc. But it is still a mono-system. Another mono-system is an eraser. Another mono-system is a pencil with another color. Bi-system is a combination of two mono-systems. So far, it is a pencil with eraser or a pencil with another color stem at the opposite end.
It is worth mentioning that bisystem properties are more than just a merge of two mono-system properties generally.

TRIZ classifies bi-systems as follows (see figure 10)

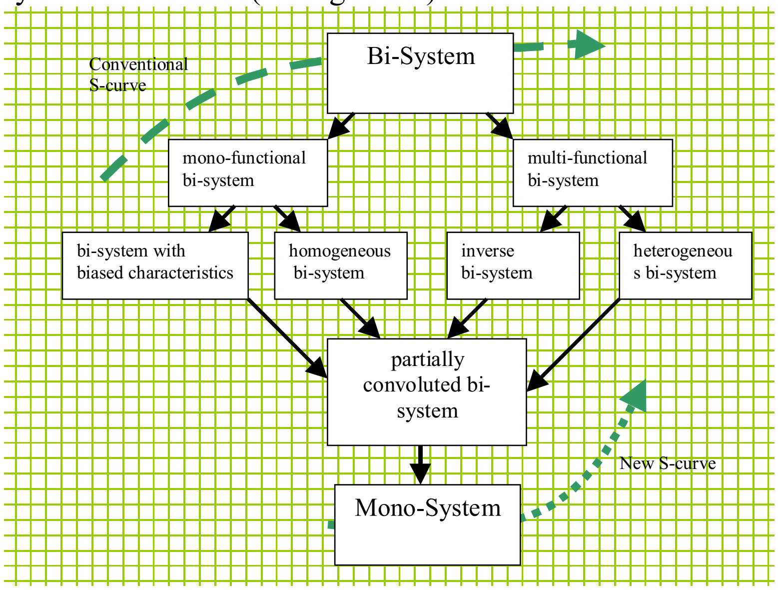

Figure 10 - Bi-system classification [Source: Chechurin L. S.: Intensive course SE]

The same classification is used for Poly-systems.
One of such trends is that one part, such as a functional part, in a system evolves into two parts, then into multiple parts, into many parts, and finally into one part at a higher level. An example of this type of evolution can be seen in the speaker system of a radio; a single speaker equipment evolved into a stereo system of two speakers, then a surrounding sound system of multiple speakers, and finally into a 3D sound system. Similarly, a gun with one bullet evolved into a double channel gun with two bullets, then a revolver pistol with several bullets, and finally into a machine gun with a large number of bullets in a belt.
Bi- or poly-system evolve by modifying the links between their components.
Example: glass sheet transportation.

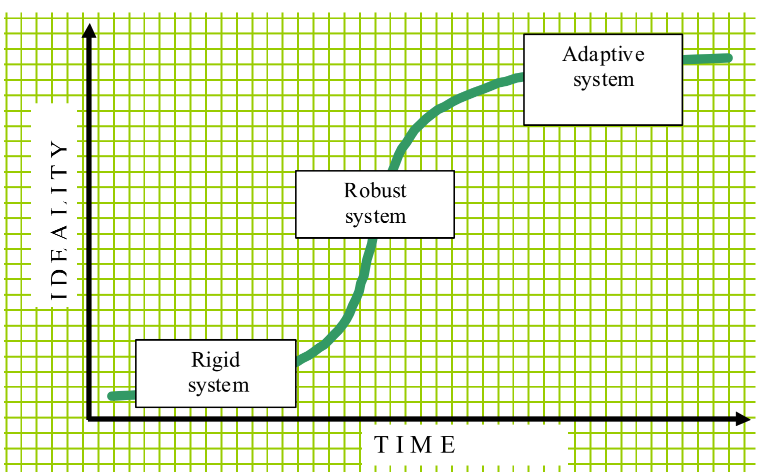

Figure 11 - Adaptivity Increase Trend [Source: Chechurin L. S.: Intensive course SE]

Having been exhausted a system evolves in a completely convoluted bi- or poly-system, when one system performs two or more functions. The convolution happens into a super-system.

It is worth mentioning that mono-bi-poly evolution should be tracked out in respect to the desired function, technical system Primary function. Thus, if the system primary function is to mark, to draw (pencil), then the system anti-function is to erase, to clean (eraser).

4.4 The trend of adaptivity increase

In the course of evolution, a technological system develops from a rigid to robust and from robust to adaptive structure.
This trend reflects the specific need of being functional within changing conditions. We should clarify that "conditions" has wider meaning here rather than just environment. It is not only a set of undesirable harmful disturbances. It is also could be a set of output requirements (functional specification). Or it could be internal changes (uncertainties) of your system. A trend of "**segmentation**" could be observed within the "adaptation" framework: e.g. working part of a system; a solid working part of a system (e.g. a metal ball in a ball bearing) evolved to divided solid parts (e.g. balls in a two-row ball bearing), then to many smaller parts (e.g. a micro-ball bearing), further to molecular scale parts (e.g. a gas bearing), and finally to the extreme of the parts using non-substance, i.e. a "Field" (e.g. a magnetic bearing system). Sometimes this working part evolution trend appears as "**Transformation toward micro-level**". Actually, we may observe solid-liquid-gas-field transition in development of many tools.
It is important to point out one thing. The chain rigid- robust – adaptive is always accompanied with the development of more and more sophisticated control system. Indeed, rigid system needs no control by definition. A robust system is almost rigid except a moment you tune it. An adaptive system changes permanently, responding to permanent environment change, control is permanently required so far.
Obviously, while approaching more and more adaptive system, make sure that your control system does reduce ideality index. Ideally, the system should be self-adaptive. Neither controller nor a human operator is needed to adjust it (patent on flexible screw pump). Thus, we may observe other trends named **automation**, controllability/observability increase.

[Source: Chechurin L. S.: Intensive course SE]

5. ARIZ

5.1 Introduction

ARIZ is an acronym for the Russian "Algorithm for Inventive Problem Solving" ARIZ is a logical structured process that incrementally evolves a complex problem to a point where it is simple to solve. ARIZ, therefore, is best used for complex problems.

Since first version of ARIZ was developed a lot of newer and more effective version throughout years. Here is presented a Russian version of ARIZ, which includes the important features of the 1977, 1985 and 1991 version.

ARIZ is considered an advanced technique of TRIZ, but it is only part TRIZ methodology. It requires precise definitions of all parts of the problem and iterative use of all the TRIZ problems solving methods as ARIZ moves you back and forth from the Functional Domain and the Physical Domain at the super-system, the system, and the subsystem levels. This elegance of "guided" problem reformulation thoroughly and elegantly defines functional requirements and necessary physical parameters of solution concepts.

Although ARIZ is meant for complex problems, begin using ARIZ on more simple problems for practice application. Notice the quality of solution you arrive at with problem you thought you were very familiar with.

5.2 Using of ARIZ

When we have complex problems, we cannot find solution only in two steps. For this kind of situation, where are problems so complex, we cannot solve with any other tools. TRIZ includes the algorithm ARIZ to follow which will facilitate the problem-solving process.

ARIZ is not only an equation, but rather a multi-step process asking you a series of questions that integrates different pieces of TRIZ. ARIZ is a very "solution neutral" process: i.e., it takes preconceived solutions out of the problem statement. It starts you at a position that assumes the nature of your problem is unknown. ARIZ reacquaints you with your problem by allowing you to see your problem with a fresh pair of eyes.

ARIZ is:
1. Process of problem reformulations
2. Logical and disciplined
3. Continual reinterprets the problem
4. The main TRIZ method for solving conflicts

Utilizes of ARIZ:

1. Ideality for an understanding of the Ideal Solution to the problem
2. Contradictions, by working first with the technical contradiction, then the physical contradiction
3. Resources of the system
4. Scientific effects
5. S-field modeling and Standard Solutions the 40 Principles Table no. 2

ARIZ is more than 50% problems reformulation. We can only through this reformulation's complex find solution and these problems can be solved.

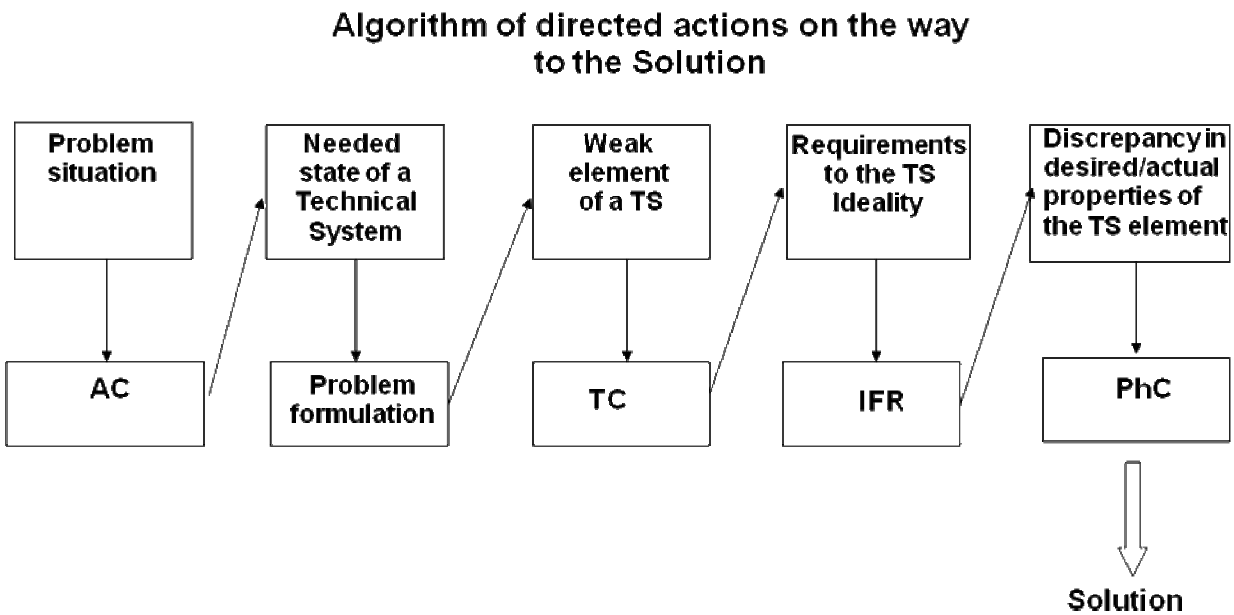

Figure 12 - Algorithm of directed actions on the way

(AC – Administrative Contradiction, TC – Technical Contradiction, IFR– Ideal Final Result, PhC – Physical Contradiction Resources for Solution)

5.3 ARIZ - step by step

1. PROBLEM ANALYSIS

Goal: *to move* ***from*** *a given situation* ***to*** *an extremely clear and simple problem model or scheme.*

1.1. Define a mini-problem

Technical system for (*indicate the system primary function*) ***includes*** (*indicate system's primary parts*).

Technical Contradiction 1*: (indicate as)

If our **TC** (or a **Tool**) is in the **State A** then the **Feature 1 is improving** but the **Feature 2 is worsening**

Technical Contradiction 2*: (indicate as)

If our **TC** (or a **Tool**) is in the **State not A** then the **Feature 1 is worsening** but **the Feature B is improving**

1.2. Define the Object and the Tool

Indicate two specific elements involved in conflict:

Element 1 – **Product** *is …….*

Element 2 – **Tool** *is …….*

Product" – an element of technical system that is supposed to be treated (produced, moved, detected, measured, protected…).

"**Tool**" – an element of technical system, that interacts with the Product directly. (heat, but not heater; glass particles but not electron gun…)

1.3. Make graphic Model of Contradiction

Draw graphic schemes of Technical Contradiction 1 (TC-1) and Technical Contradiction 2 (TC-2).

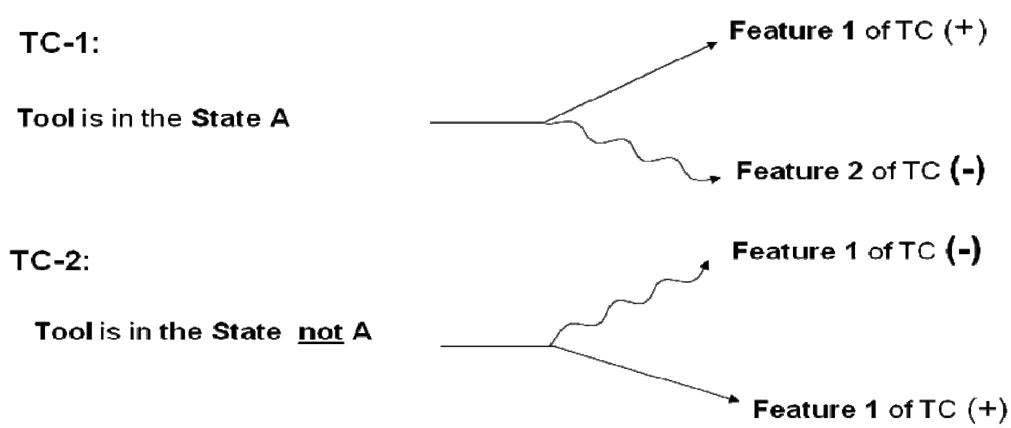

Figure 13 - Model of Technical Contradiction

1.4. Choose one from two schemes of conflicts which **provides** realization of the **main useful function**.

1.5. Intensify the conflict. Replace "many elements" by "infinite number of elements", "small amount of elements" by "no elements", "more inflexible" by "solid" etc.

1.6. Define the feature of the TS which is necessary to improve, and the feature which thus worsens. **Choose in the Table of Typical Principles** for TC elimination (Altshuller's Matrix) parameters - analogues and determine **recommended** typical **principles** for the TC elimination.

1.7. Check up an opportunity of application of **Inventive Standards** to the solution of a problem. If the problem is not solved go on the second part of algorithm.

2. PROBLEM MODEL ANALYSIS

***Goal**: Revealing of available resources which can be useful for solution of a problem (substance, field, spatial, time resources).*

2.1. Define the **Operational** Zone (OZ) – space where the conflict occurs
2.2 Define **Operational Time** interval (OT) – the time of conflict (OT-1) and the time before conflict (OT-2)
2.3. Define and analyze substance and field resources.
1. **Substance and field resources (SFR)** are the substances and the fields that are already available or can be obtained easily according to the problem conditions.
2. **Product is unchangeable element** of TS. However the product can be a source of **SFR** if it can be changed easily (spending of any part of a product when there are a lot of the product, e.g. water in the river, the wind, etc.)
3. **While solving each mini-problem**, it is desirable to achieve the result with minimal **using of SFR.** Therefore, **internal SFR** should be used first, then **external SFR** and at last **super-system SFR.**

3. IDEAL FINAL RESULT and PHYSICAL CONTRADICTIONS

***Goal:** to formulate ideal solution (IFR) and define the Physical Contradiction that does not allow us to reach IFR.*

3.1. Formulate the **Ideal Final Result (IFR-1)**
3.2. Formulate the **Physical Contradiction** (PhC)
3.3. Intensify Ideal Final Result 1 to **IFR-2:**
Harmful effect has been eliminated without any new SFR introduction to the system; only the SFR of the TS are used.
3.4. Formulate IFR-2 on **Macro level**:

3.5. Formulate IFR-2 on **Micro level**
The first three parts of ARIZ rebuilds the initial problem dramatically. As a result the real inventive situation is formulated: "Everything remains without changes or becomes simpler, but thus there is a required action (property) or harmful action (property) disappears".

After IFR-2 has been formulated in 3.4 we have to solve a specific physical problem instead of initial diffused problem.

4. SUBSTANCE-FIELD RESOURCE MOBILIZATION

Goal: *The idea of this part is to introduce as few substances as possible into the system. If existing SFR cannot be used in the state there exist, they should be changed.*

4.1. Introduction of new substance in the system. SFR should be examined in the following order:

- SFR of the tool;
- External SFR;
- Surrounding SFR;
- SFR of the object.

4.2. Define whether the problem is solved with application of a **mix of resource substances**.
4.3. Define whether the problem is solved with **replacement** of available resource substances **with emptiness** or a **mix of resource** substances with emptiness.

Void - extremely important resource. It always is present in unlimited amount, it is almost free of charge, easily mixes up with available substances, forming foam, bulbs and so on.
4.4. Try to use the **substances derived** from resource substances (or a **mixture** of derivative substances **with a void).**
4.5. Try to use a **field or interaction** of two fields i**nstead of a substance.** Use the pair: **"field - field-sensitive addition".**

5. APPLY EXPERIENCE AND DATABSES (USE TRIZ INFORMFUND)

Goal: *use of previous experience concentrated in TRIZ Information Fund*

5.1. Define whether the problem with use of Inventive Standards can be solved, including using Typical Principles of TC elimination.
5.2. Consider an opportunity of the problem solution on the analogy of non-standard problems solved earlier according to ARIZ.

5.3. Define, whether the problem is solved with application of Typical Principles of PhC elimination.
5.4. Apply Databases of Physical Effects ("Techoptimizer" software).
5.5. Consider opportunities of geometrical and chemical effects application.

6.- CHANGE AND/OR REPLACE THE PROBLEM

Goals: Transition from the physical answer, technical idea to the technical solution, but if the solution is not present - to make updating a problem.

6.1. If the physical problem is solved – try to find a way to technical realization:

- Formulate the method to idea realization
- Make the design draw of idea implementation.

6.2. If solution is not found – go to 1.4. Try to resolve the contradiction TC-2 instead of TC-1.
6.2. If solution is not found - check if initial problem formulation is a mixture of a few tasks or one problem only. If the problem consists of few tasks then try to make out the row of single problems and then to solve them one after another.
6.3. If solution is not found, change a problem, having formulated another TC (a step 1.1. - 1.4.)
6.4. If there is no solution of initial problem – return to a step 1.1., having formulated a new problem.

7. - ANALYZE THE METHOD FOR PHYSICAL CONTRADICTION ELIMINATING

*Goal**:** check a quality of solution found*

7.1. Check the solution**.**
Consider substances and fields, which were included to system for the solving. Is it possible or not to use system's substance and field only, without any "foreign"?

7.2. Estimate of solution.
Answer the next questions:
1) Is the solution in accordance with the main requirement of IFR
2) What physical contradiction has been eliminated?

7.3. Evaluate novelty.
Check if your solution is novel (patent application).
7.4. Consider implementation consequences
Analyze what technical difficulties could appear while implementing the obtained solution.

8. - APPLICATION OF THE PROBLEM SOLUTION

Goal: *Maximal use of resources of the found idea.*

8.1. Define how should be changed Subsystem to which the changed TS belongs.
8.2. Check up whether changed TS can be used in the other application.
8.3. Consider application of the received solution for the solving of other problems:
a) Formulate in general form the received principle of the solution;
b) Consider an opportunity of direct application of the found principle for solving of other problems;
c) Consider an opportunity of use of a principle, inverse to the found one.

6. Case study – Kryotherm Company

6.1 About company

Kryotherm was founded in 1992 on the basis of the large research and development institute that designed thermoelectric modules (TEMs) and related subsystems for the needs of the Army and aerospace industry. The company has taken the leading position in the world thermoelectric market since the very beginning due to its great scholarly potential and modern management techniques employed. At that time Kryotherm goals have been re-oriented at its products civil applications as well. At present Kryotherm staff numbers 200 employees. 13 of them hold Ph.D. degree.

Since the very beginning, Kryotherm has carved a unique niche in the thermoelectric high technology market due to our adhering to the company's mission, which are:

- To design and manufacture highly efficient and reliable thermoelectric products;
- To carry out scientific research to expand the reach of our technology as well as to make enhancements to the existing product items;
- To create the right thermoelectric solutions for our customers;
- To offer the best customer-orientated services to meet all the expectations of our clients.

Kryotherm constantly widens its product range. Today we manufacture over 250 types of regular TEMs. Design and manufacturing of custom TEMs and related subsystems is another Kryotherm core business. Our forty-year experience in the field of thermoelectricity enables us to offer our clients the most effective solutions to fully meet their needs and requirements.

Besides, our high production capacity enables us to remain cost competitive and Kryotherm has a well-earned reputation for product reliability and longevity. The company's financial stability, high quality of the goods produced and our expertise in the field of thermoelectricity have helped us significantly to be ranked among the most reliable and trustworthy partners.

[Source: http://www.kryotherm.ru/]

6.2 Description of Problem

Kryotherm Company has a problem with the production of its thermodynamic modules (figure no 1.). More specifically, it is having problems with the grinding of porcelain covers to a specific depth. In this process ceramic squares are laid out on a surface (figure no. 4), from which a grindstone moves up and down. With an ideal depth of 3 mm, a system for improved control and monitoring of grinding needs to be designed. Currently, a worker must visually approximate the depth of grinding while it is in process, then stop the process when judged suitable in order to take actual measurements with a micrometer (Figure no. 3). If the measurements are outside the allowable range of tolerance, the grinding will need to be repeated. We would like to automate this procedure using a TRIZ methodology called ARIZ in order to improve the grinding accuracy of the system. We will demonstrate with an example how this methodology works.

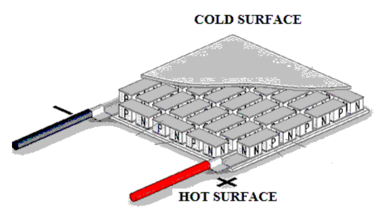

Figure 14 - Thermoelectric module I.

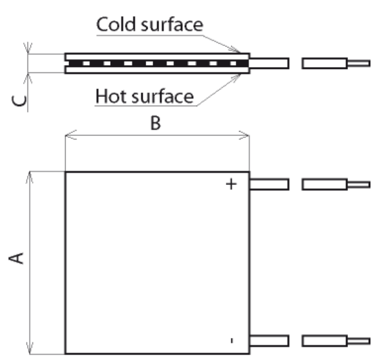

Figure 15 - Thermoelectric Module II.

Figure 16 - System of measurement

Next photos from manufacturing, process of grinding, and other equipment, you can see in attachment 10.1 and 10.2 in this work.

6.3 Example of Modeling of grinding system

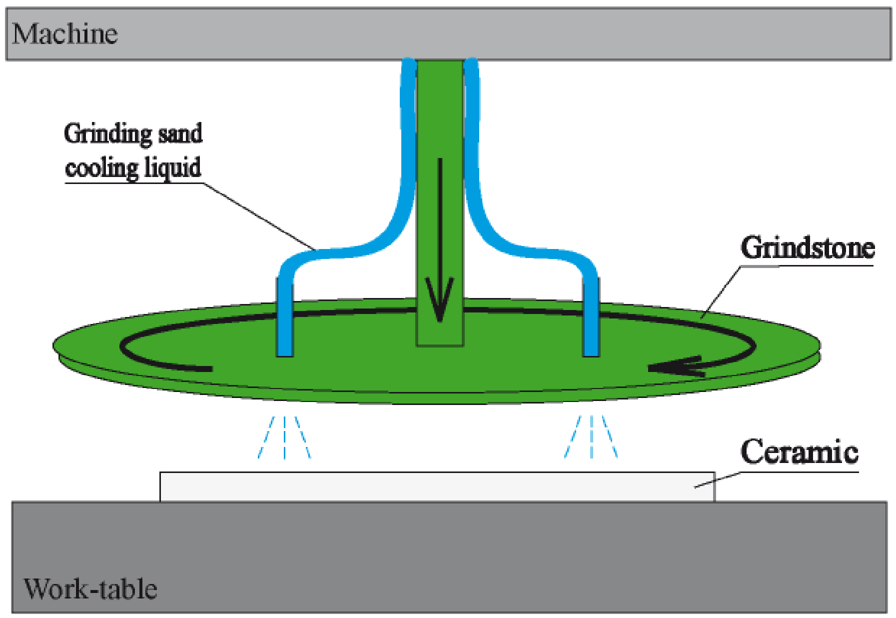

Figure 17 - Example of modeling of grinding system

6.4 Technical system of grinding

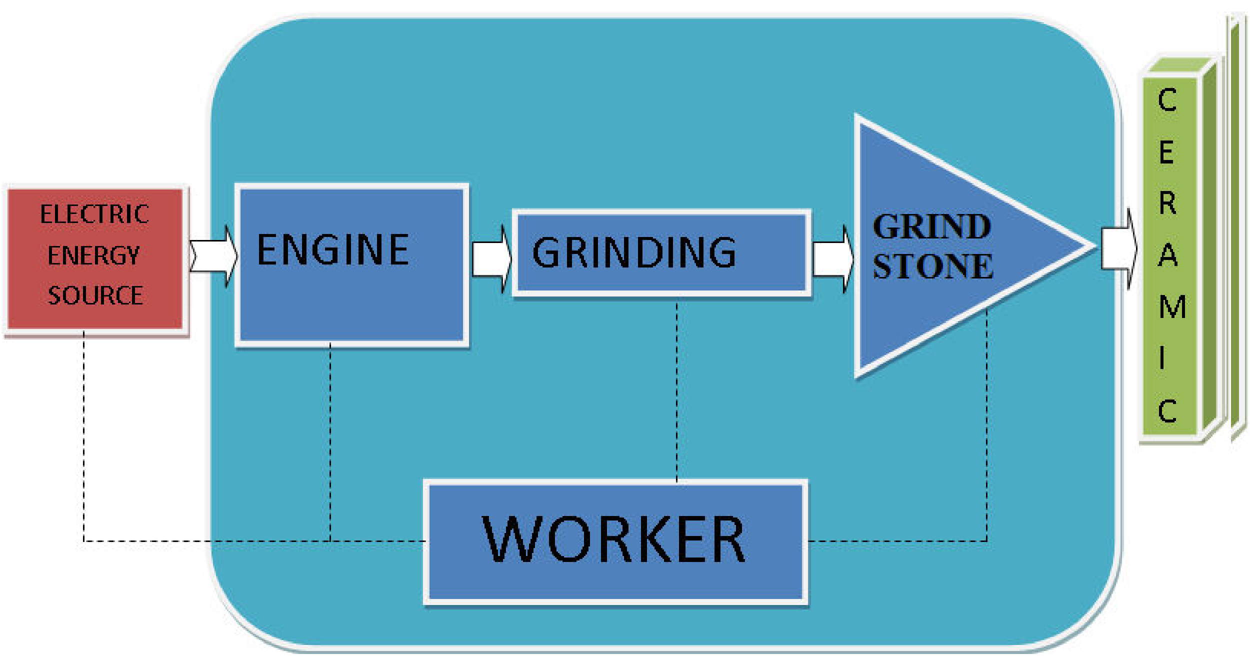

Figure 18 - Technical system of grinding

6.5 Real problems

Problem is to find a solution for automating system for measurement the grinding of ceramic covers used in thermoelectric modules.

Problem is to find solution for increasing efficiency of cooling system and faster grinding of ceramic covers used in thermoelectric modules.

Problem is to find solution for increasing productivity with same technical background.

6.6 Solving by ARIZ

1. PROBLEM ANALYSIS

Technical system for measurement ceramic substrates for thermoelectric modules **includes** grindstone, grinding sand, ceramic, source of turning, cooling liquid, cooling pipes, water jets, work-table, micrometer,

<u>Technical Contradiction 1:</u>

If our **Measurement's time of depth** is **increased** then the **Accuracy is improving** but the **Productivity is worsening**

<u>Technical Contradiction 2:</u>

If our measuring system (micrometer) measures more pieces of ceramic in one time then the **productivity is improving, but accuracy for one piece is worsening.**

<u>Technical Contradiction 3:</u>

If our distance between measurement system **(micrometer) and grinding machine is shorter then the duration of operation is improving, but accuracy of measurement is worsening, because of vibration.**

<u>Technical Contradiction 4:</u>

If our measurement of ceramic modules is doing with higher frequency then accuracy is improving, but duration for operation is worsening.

<u>Technical Contradiction 5:</u>

If our measuring system is implement in grinding machine then the **productivity is improving, but accuracy is worsening.**

1.2. Define the Object and the Tool

Element 1 – **Product** is Ceramic

Element 2 – **Tool** is Measuring system

1.3. graphic Model of Contradiction

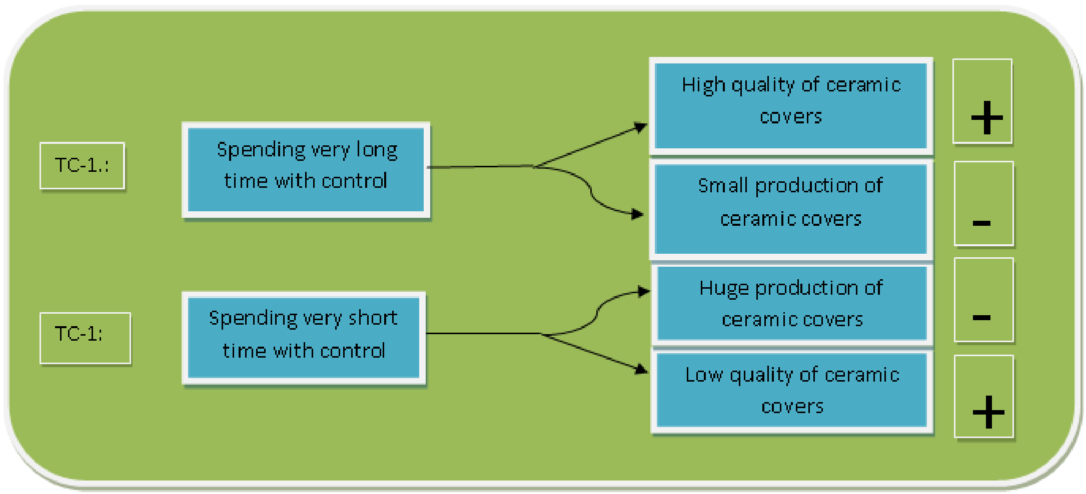

Figure 19 - Scheme of conflict

1.4. Choose one from two schemes of conflicts which **provides** realization of the **main useful function**.

I recommend use first contradiction, because Quality is more important than quantity.

1.6. Define the feature of the TS which is necessary to improve, and the feature which thus worsens. **Choose in the Table of Typical Principles** for TC elimination (Altshuller's Matrix) parameters - analogues and determine **recommended** typical **principles** for the TC elimination.

Parameters - analogues on Altshuller's Matrix:

Measurement accuracy – production

2. PROBLEM MODEL ANALYSIS

2.1. Define the **Operational** Zone (OZ) – Measuring depth

2.2 Define **Operational Time** interval (OT) –Time of Measurement

2.3. Define and analyze substance and field resources.

Ceramic, source of turning, water yet,

Resources: Electric energy, water.

3. IDEAL FINAL RESULT and PHYSICAL CONTRADICTIONS

3.1. Formulate the **Ideal Final Result (IFR-1)**

The Ideal Final Result is to produce ceramic substrates for thermoelectric modules with exact depth with no manual measurement. The machine will provide automatic measurement, determine depth of the ceramic covers and discontinue grinding.

3.2. Formulate the **Physical Contradiction** (PhC)

PhC-1:

Time of the measurement must be enough long for accurate controlling depth of ceramic substrate, but It has to be short for optimal production.

PhC-2:

Grinding sand and cooling must be cleanable from ceramic substrates for measurement, but it has to be still effective for grinding.

PhC-3:

Measuring system must be implement in grinding system for decreasing duration of production, but the measuring system must be enough accurate for controlling depth.

3.3. Intensify Ideal Final Result 1 to **IFR-2** :

1. Harmful effect has been eliminated without any new SFR introduction to the system; only the SFR of the TS are used.

   OZ should be clean for measure depth and shouldn't be very clean, because of cleaning time

4. SuField Analysis - SUBSTANCE-FIELD MODELS

In this case we must use Subfield analysis – Class for measurement problems. Graphic model of this analysis is on figure 20. This analysis helps us understand interaction between contradictions. It can help us exploit their positive effect. Their negative effects will be minimized or exploited for solving problem.

1. F-Field: Measuring accuracy
2. S1-Product: Ceramic
3. S2-Tool: Measuring system

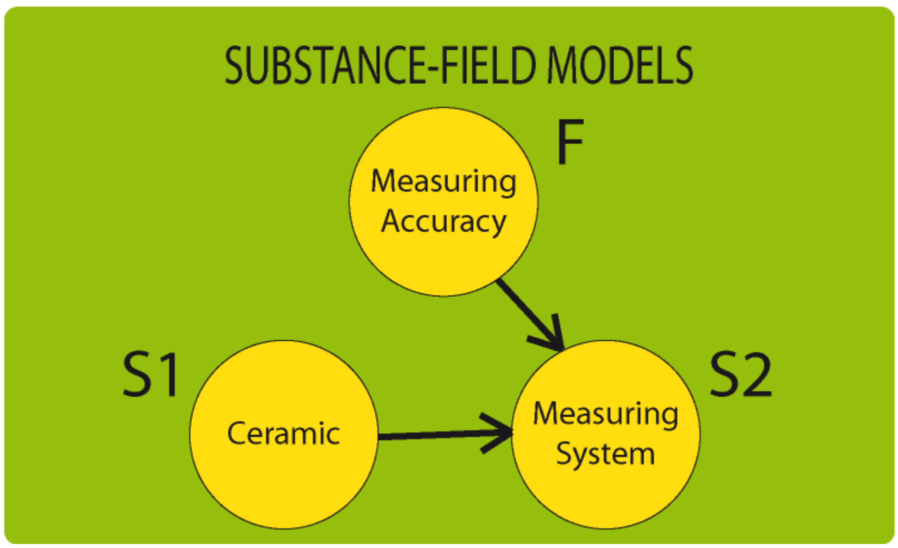

Figure 20 - Model of SubField analysis

Conceptions:

The most IDEAL SOLUTION would be "No exact depth is needed any more" – this is the model of solution. Any idea how to make it possible? (realization)

FINAL SOLUTION for measurement system. No system, but the thickness is ensured – this is a model. Any technical idea to make it happen (realization)?

"Almost IDEAL SOLUTION" – we still need measurement but we do not need time-consuming process/equipment for that. "Ceramic ITSELF tells its thickness" –this is a model. Any technical ideas for that (Realization)?

7. Conclusion

The main goal of this work is to introduce methods of improving/optimizing (Six-Sigma, Lean, TQM, and QFD) and inventive technology TRIZ. Ideal way to introduce TRIZ, Theory of Solving Inventive Problems, is to divide it into four main steps which are following:

1. Real problem
2. Modeling
3. Modifying
4. Realization of solution

Almost all parts and tools of TRIZ are presented on examples, because it is the easiest way to understand problematic and TRIZ "thinking".

I applied theoretical knowledge on small electrical manufactures in Kryotherm Company and helped them find solution for measurement thermoelectric modules.

Real problem is already taken from the process of production of thermoelectric module. I used algorithm ARIZ for solving this problem, and I used it exactly the way which is described in this work.
Firstly, I formulated model of technical system and set problems for solving. After that we continued by ARIZ. I formulated definition of technical system, and Technical contradictions. The best choice was to use contradiction between parameters measurement accuracy and productivity by analogues on Altshuller's Matrix. If the duration of measurement is increased, accuracy is improving, but productivity of production is worsening.

After that we set Ideal Final Result:

The Ideal Final Result is to produce ceramic substrates for thermoelectric modules with exact depth with no manual measurement. The machine will provide automatic measurement, determine depth of the ceramic covers and discontinue grinding

In the final step we made SuField analysis and set conceptions of ideal solutions. The main one is:

The most IDEAL SOLUTION would be "No exact depth is needed anymore"

This work is supposed to be a manual useful to understand theory of improving/ optimization and solving innovative problem TRIZ, with description of leading process innovative design for finding final solution and helpful material for understanding innovation.

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9. List of Figure, Tables and Acronyms

9.1 List of Figure

9.2 List of Tables

9.3 Acronyms

QFD – Quality Function Development

TQM - Total quality management

TRIZ – Theory of solving inventive problems

IDF- Ideal final result

ARIZ – Algorithm for Inventive Problem Solving

TS- Technical System

TESE – Trends Technical system of evaluation

TC – Technical contradiction

PhC- Psychical contradiction

SSE – Sematic Search Engine

10. Attachments

Photos of Thermoelectric modules

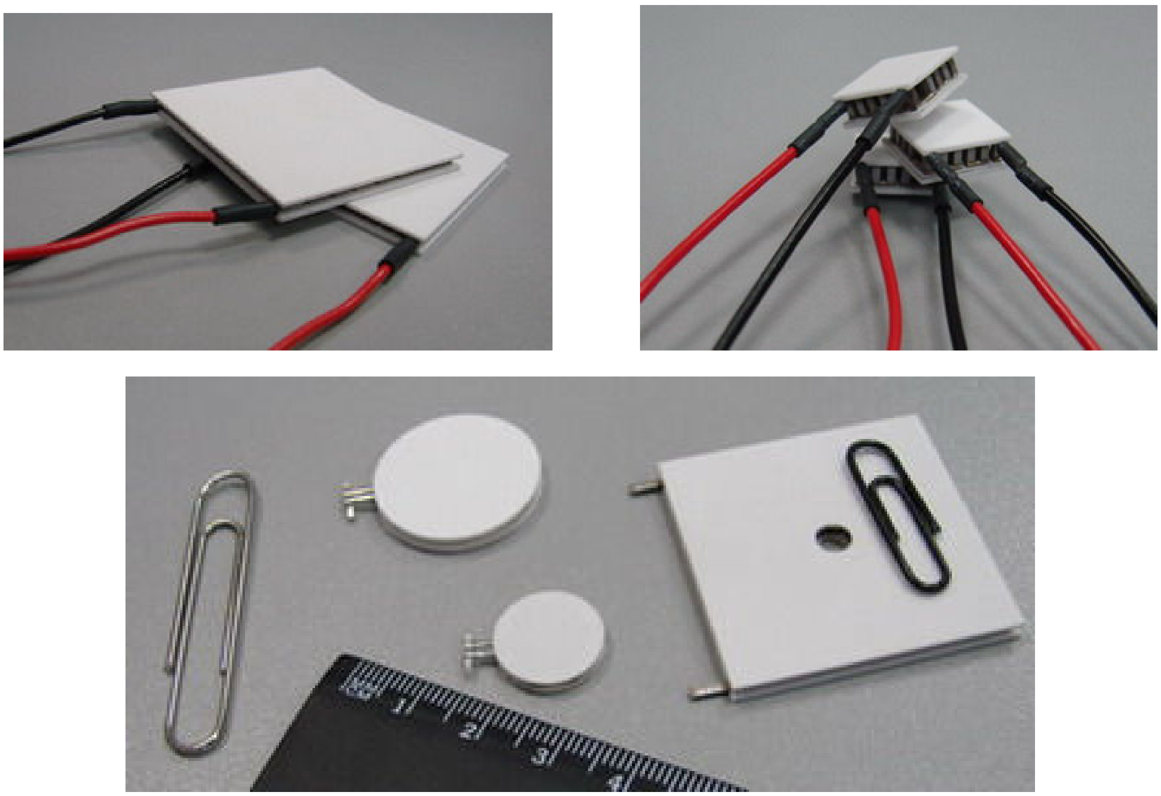

Figure 21 - Photos of thermoelectric modules

Production of thermoelectric modules

Figure 22 - Ceramic prepared for grinding

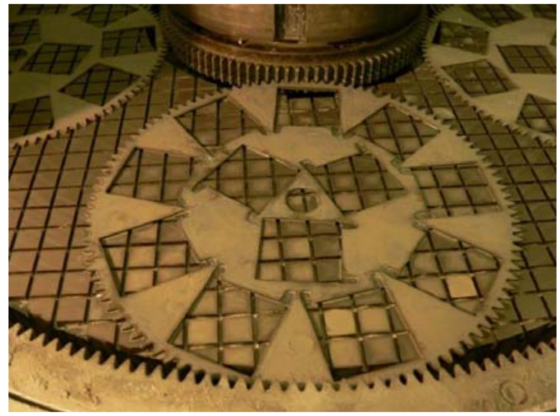

Figure 23 - Form for ceramic

Figure 24 - Grinding system