FACULTY OF MECHANICAL ENGINEERING

DEPARTMENT OF MACHINERY

DESIGN AND FEASIBILITY STUDY OF PRODUCTION LINE FOR ROUNDING OF SHARP EDGES ON PROFILES

PROFIILIDEL TERAVATE SERVADE ÜMARDAMISEKS TOOTMISLIINI KONSTRUKTSIOONI JA TEOSTATAVUSUURING

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AUTHOR'S DECLARATION

I have written the Master's thesis independently.

All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's thesis is completed under... supervision

“.......”....................201….. Author .... signature

Master's thesis is in accordance with terms and requirements

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Accepted for defence

....Chairman of defence commission

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MASTER’S THESIS OBJECTIVE AND TASK

2015/2016 academic year, 1st semester

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MASTER’S THESIS TOPIC:

Design and feasibility study of production line for rounding of sharp edges on profiles

Profiilidel teravate servade ümardamiseks tootmisliini konstruktsiooni ja teostatavusuuring

TASKS AND TIMEFRAME:

№	Task description	Completion date
1.	Carrying out a study of theoretical and practical information related to the problem of rounding of sharp edges on specific profile types.	23.10.2015
2.	Collection and compilation of statistics and economic indicators on the example of the company Marketex Offshore Construction OÜ (hereinafter M.O.C.).	7.11.2015
3.	Search, comparison and analysis of equipment and technical solutions on the market.	23.11.2015
4.	Design and development of the concept of equipment or machinery for rounding of sharp edges on specific profile types.	7.12.2015
5.	Preparation of the final technical documentation.	28.12.2015

DESIGN AND ENGINEERING PROBLEMS TO BE SOLVED:

The main objectives of this Master's thesis are review and analysis of equipment and technological methods of rounding of sharp edges of a certain type of metal profiles. Covering both economic and technical indicators of existing solutions the final goal will eventually be development of equipment capable to solve the posed problem and feasible in the current manufacturing capabilities.

Defence application submitted to deanery not later than			14.12.2015
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1. INTRODUCTION

Corrosion is one of the factors having a negative effect on such materials as metals. In a majority of manufacturing and construction industries, iron and its alloys are the most used metals over the years. Being at the continuous environmental exposure (water, air and soil), steel is subject to the disruptive effect of corrosion. So, in order to prevent the corrosion wear and emergent defects, the steel structure surfaces are protected by the special coatings, paints and other methods. The efficacy of protective coats is closely linked to the following conditions of the steel surfaces:

- Existence of rust and mill scale (for example in case of hot rolling).
- Presence of surface contamination (including salt, dust, oils and lubricants).
- Geometry and profile of surfaces (sharp edges, roughness, welding seam and splashes).

Generally, the defects of welding seams, edges and other parts of steel objects become the sources of corrosion. Such areas are difficult to protect from the environment by means of painting and coating, moreover they are inevitable in an industry linked to metals due to the imperfection of equipment and individual himself.

The specialised and experienced organisations develop standards and procedures in order to avoid a critical number of defects and to control the surface conditions. Different regulations and Classification Societies are applied according to the geographical location, history and activities of an enterprise. In Europe, the standards of the following organisations are used for the machinery and manufacturing of large-sized steel structures: DNV-GL (Det Norske Veritas - Germanischer Lloyd), ABS (American Bureau of Shipping), NORSOK (Norsk Sokkels Konkuranseposisjon), ISO (International Organization for Standardization).

Instructions and recommendations on painting, described in the documents of the above mentioned organizations, cover a great number of criteria and among them there is a rounding or blunting of sharp edges to provide more firm adherence between protective coats and base material. The blunting is considered to be a less effective method of control over the corrosion because it leaves cutting edges. Therefore, the rounding with radii settled by the equipment designer following the standards is preferable. The radius of two or three millimetres is the most common for rounding of sharp edges.

1.1. Range of problems

The mechanisation of hand work strengthened in civilisation, for that reason the equipment is developed exponentially and the more advanced it becomes, the higher rating of effectiveness and easy handling are required for machines. This is particularly so with the industries related to the metals mining and processing that have different physical, chemical and geometrical characteristics. For instance, one of the most used methods of steel processing is rolling by means of which it is possible to obtain the following range of products: flat products, pipes, special purpose profiles and long products which require the use of different processes and equipment.

Particular attention should be paid to the profiled bar due to its complex structure of section shape. The use of profiles of this group, such as T-beam, I-beam, U-channels and angles, is very common in the machine industry. The geometry of the profiled bar comprises the sharp edges which require the rounding before applying coats that protect metals against corrosion. Due to the form differentials, emerges the problem of choosing which equipment to use and the companies spend enormous assets for this issue. Despite the seriousness and exploration degree of this problem, the edge rounding continues to be an ineffective and expensive procedure.

The economic indicators of the companies involved to the metal industry directly depend on the applied technologies and processes so that development and improvement of equipment fall within the field of their interests. A good example is Estonian concern BLRT GRUPP, one of the largest industrial centres in the Baltic Sea region, whose services include metal forming, machine building, production of complex metal constructions and painting. The company Marketex Offshore Constructions, being part of the concern and also closely associated with these fields, offers large-sized complex solutions for the offshore oil and gas markets. The output product comprises diverse materials, but generally, it is low-carbon alloy steel. The pursuit of development and willingness to share experience led the concern to prosperity. Therefore, drawing attention to the problem of sharp edges rounding on steel products, the company management has defined the task to search and to study an effective and simple solution as well as to implement it into the operation environment.

1.2. Goals and Objectives

The object of research of the present scientific paper is rounding of sharp edges of metal profiles obtained by rolling. Being a very deep and multifaceted matter, attention will be given primarily to the baseline aspects such as rolling of machine-building profiles, types of rolling, condition and protection of surface. Secondly, the statistics of material utilization and related economic indicators of the company Marketex Offshore Constructions will be provided.

The obtained theoretical and practical knowledge will lead to the achieving of two goals, namely, the review and analysis of equipment and processing methods of rounding of sharp edges offered by the market. The ultimate goal of this graduate thesis will be development of universal equipment able to solve the stated problem more efficiently than analogues available on the market, taking into account the possibility of its implementation to the concern and feasibility by means of the actual production technologies.

1.3. Process Methodology [1]

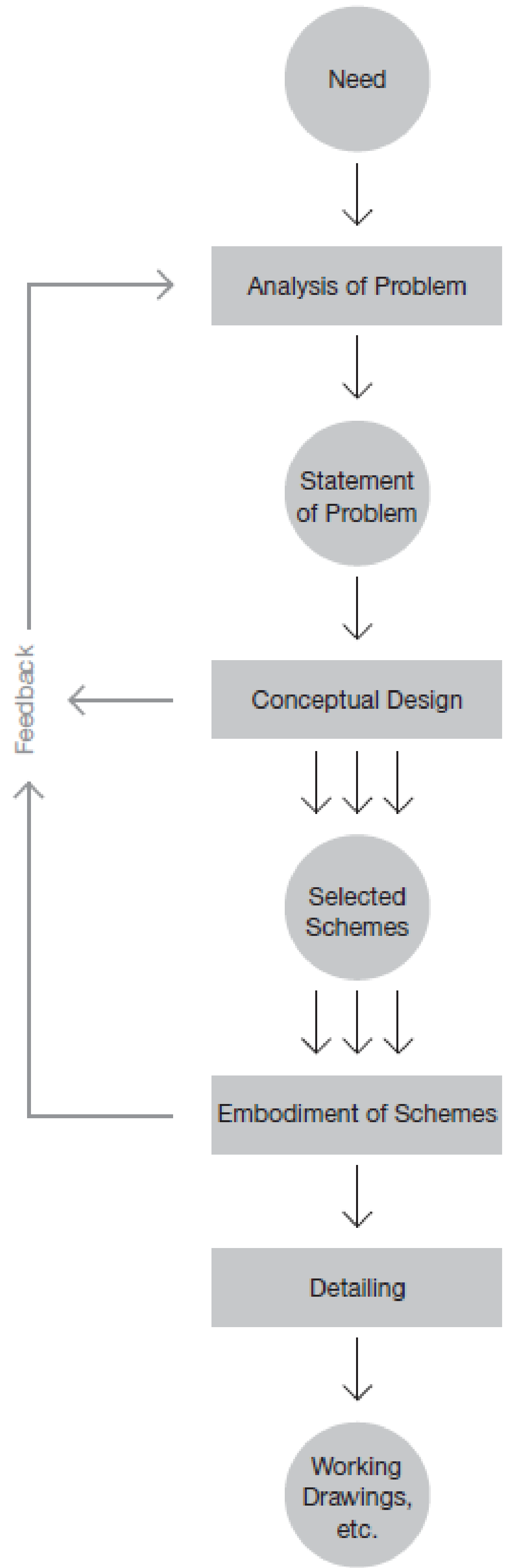

Figure 1 – Block diagram of design process

Figure 1 is a block diagram showing the design process according to the Michael J. French. Circles represent stages reached, and the rectangles represent work in progress.

Constructing block diagrams is a fashionable pastime, especially in fields like design where boundaries are imprecise and interactions legion, so that any ten experts will produce ten (or a hundred). They will all be different, and all valid' there are nine and sixty ways of constructing tribal lays, and every single one of them is right.' They express only truisms, and yet they have a value for all that.

In this particular block diagram things that are important but outside the scope of this book have been omitted-for example, relationships with other activities like research and development, inputs of information and so forth. On the other hand, there is no box labeled 'evaluation' because the writer believes it should be going on continuously in all the rectangles.

Analysis of the problem

This part of the work consists of identifying the need to be satisfied as precisely as is possible or desirable. For such things as consumer goods or widely used items of machinery, it is a problem of locating and defining an adequate 'ecological niche' and this is the hardest case. The analysis of the problem is a small but important part of the overall process. The output is a statement of the problem, and this can have three elements:

- Statement of the design problem proper
- Limitations placed upon the solution, e.g. codes of practice, statutory requirements, customers' standards, date of completion, etc.
- The criterion of excellence to be worked to

Conceptual design

It takes the statement of the problem and generates broad solutions to it in the form of schemes. It is the phase that makes the greatest demands on the designer, and where there is the most scope for striking improvements. It is the phase where engineering science, practical knowledge, production methods and commercial aspects need to be brought together and where the most important decisions are taken.

Embodiment of schemes

In this phase the schemes are worked up in greater detail, and if there is more than one, a final choice between them is made. The end product is usually a set of general arrangement drawings. There is (or should be) a great deal of feedback from this phase to the conceptual design phase, which is why the writer advocates overlapping the two.

Detailing

This is the last phase, in which a very large number of small but essential points remain to be decided. The quality of this work must be good, otherwise delay and expense or even failure will be incurred: computers are already reducing the drudgery of this skilled and patient work and reducing the chance of errors, and will do so increasingly.

This brief description of the design process will suffice for present purposes. Apart from organizational problems, the difficulty of maintaining the quality of detail draughting, and so forth, there are three central problems in design:

- Generation of good schemes (conceptual design)
- Securing the best embodiment of those schemes (the problem of best embodiment)
- Evaluation of alternatives

1.4. Engineering Design Methodology [2]

In order to solve a technical problem, we need a system with a clear and easily reproduced relationship between inputs and outputs. In the case of material conversions, for instance, we require identical outputs for identical inputs. Also, between the beginning and the end of a process, for instance filling a tank, there must be a clear and reproducible relationship. Such relationships must always be planned—that is, designed to meet a specification. For the purpose of describing and solving design problems, it is useful to apply the term function to the intended input/output relationship of a system whose purpose is to perform a task.

For static processes it is enough to determine the inputs and outputs; for processes that change with time (dynamic processes), the task must be defined further by a description of the initial and final magnitudes. At this stage there is no need to stipulate what solution will satisfy this kind of function. The function thus becomes an abstract formulation of the task, independent of any particular solution. If the overall task has been adequately defined that is, if the inputs and outputs of all the quantities involved and their actual or required properties are known—then it is possible to specify the overall function.

An overall function can often be divided directly into identifiable sub functions corresponding to subtasks. The relationship between sub functions and the overall function is very often governed by certain constraints, inasmuch as some sub functions have to be satisfied before others. On the other hand, it is usually possible to link sub functions in various ways and hence to create variants. In all such cases, the links must be compatible.

The meaningful and compatible combination of sub functions into an overall function produces a so-called function structure, which may be varied to satisfy the overall function. To that end it is useful to make a block diagram in which the processes and subsystems inside a given block (black box system shown on Figure 2) are initially ignored, as shown in Figure 3.

Functions are usually defined by statements consisting of a verb and a noun and are derived for each task from the conversions of energy, material and signals. So far as is possible, all of these data should be accompanied by specifications of the physical quantities. In most mechanical engineering applications, a combination of all three types of conversion is usually involved, with the conversion either of material or of energy influencing the function structure decisively. An analysis of all the functions involved is always useful.

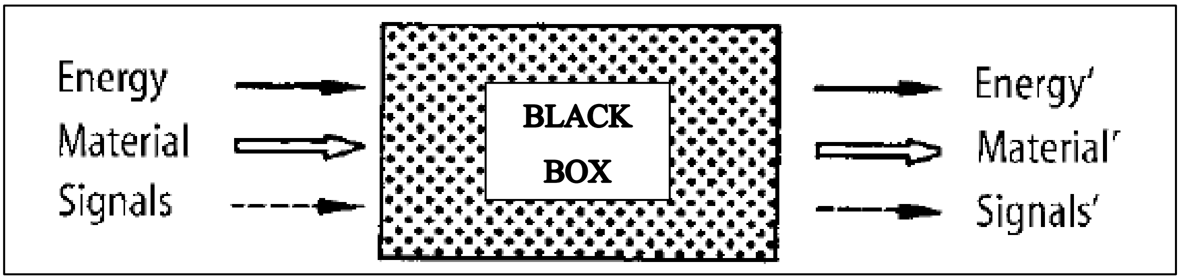

Figure 2 – The conversion of energy, material and signals. Solution not yet known; task or function described on the basis of inputs and outputs

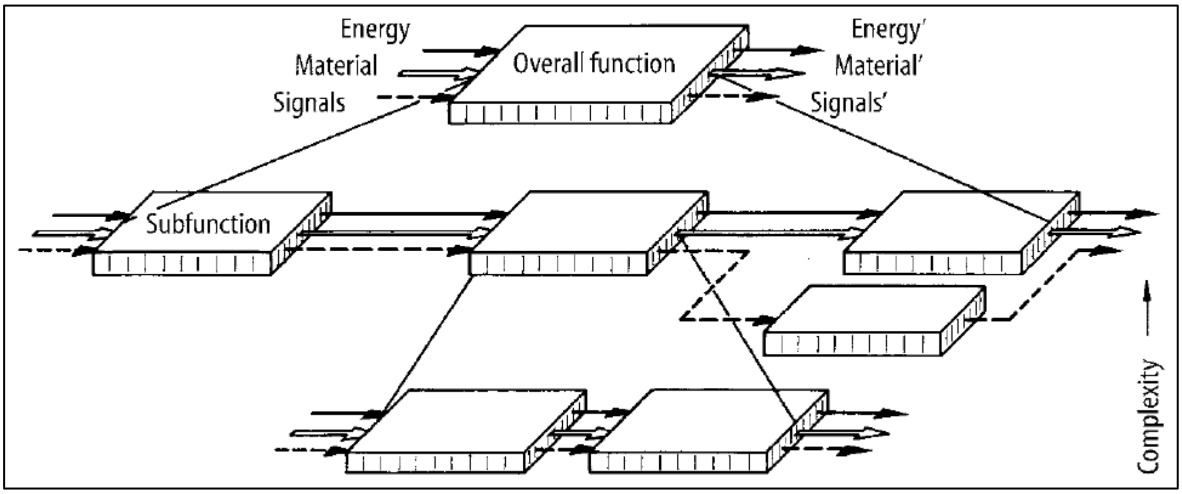

Figure 3 – Establishing a function structure by breaking down an overall function into sub functions

2. BACKGROUND

2.1. Metal-forming Process

The forming is based on the capability of billets from metals and other materials to deform non-destructively their form under the action of outside force. The metal-forming process is one of the progressive, economic and high-capacity methods of billets production in the machine-building and instrument-making industries. Almost 90% of all smelted steel and 60% of non-ferrous metals and alloys are subjected to one or another method of forming — rolling, blanking, drawing, forging, die forging or sheet stamping. In comparison with other production methods of billets, the metal-forming processes stand out with high efficiency and they are relatively easy to automate.

Using metal forming one can obtain billets and parts from materials possessing plasticity, i.e., to become irretrievably and non-destructively deformed under the action of outside force. When forming, the plastic working transfers to cast metal the higher mechanical characteristics, transforming its structure and rectifying its defects, thus increasing the life time and operational factors of the machine components. [3]

2.1.1. Types of Metal-forming Processes

According to the thermomechanical mode of working, the following types of the plastic working are distinguished: cold working at which hardening occurs and softening is absent; partial cold or like cold working when hardening and softening occur in consequence of return; partial hot working, at which hardening and fractional (partial) recrystallization occur, i.e., incomplete softening; hot working, when hardening and almost absolute crystallization occur, i.e., complete softening. [3]

It is the practice to divide all operational procedures of metal forming into the processes closing the metallurgical cycle (rolling, blanking, drawing) and production processes for preparation of parts and finished pieces utilised in machine building (forging, hot stamping, cold stamping, warm forging, local loading stamping, sheet-metal forming, knurling and other specialised processes). [4]

There are currently about 400 methods of the bulk forming and the further works on development and implementation of new, low-waste methods of billets producing with fairly precise dimensions and low surface roughness. [4]

2.1.2. Rolling

Rolling is a type of forming when the part billet, i.e., ingot or cast, under the action of friction forces retracts constantly between the revolving rollers and becomes plastically deformed with the decrease in thickness and with the increase in length and width. Figure 4 shows schematically this process. Almost 90% of all smelted steel and a large part of non-ferrous metals are subjects to the rolling, as well as this type of metal forming processes is close to the machinery and manufacturing of large-sized metal products.

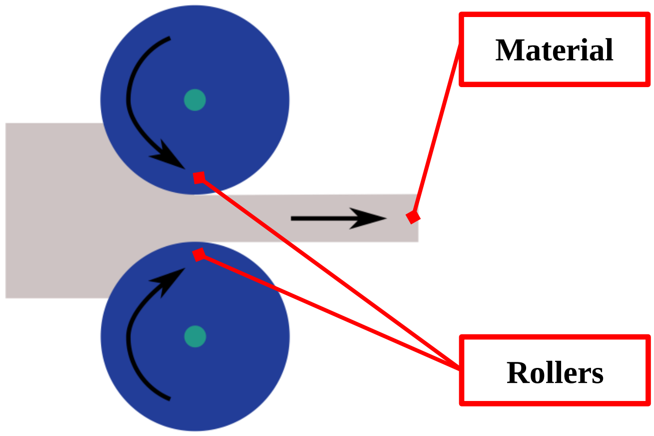

Figure 4 – Simplified representation of rolling [5]

Rolling allows producing of products at the lowest unit costs which either fully reproduce cross-sections prescribed by the designer or approximate maximally to them. Rolling has higher technical-economic values in comparison with other methods of metals processing, namely, high efficiency, low-cost and high utilisation of metal. Billets made by means of rolling are used for direct production of details on cutting machines and for the manufacturing of forged products. [6]

2.1.3. Profile and Range of Products

The cross-sectional shape of products obtained by means of rolling is called profile. The assemblage of forms and dimensions obtained by rolling is called range of products. The range of products is divided into the following groups: long product, flat product, pipes and special purpose profiles.

In its turn, long product may vary in section shape and is divided into simple, i.e. long product of geometrical shape: round, square, hexagon and others; profiled: angles, T-beams and I-beams, rails, U-channels, etc. (Figure 5). Sheet metal or flat products are divisible conditionally into thick (from 4 mm and more) and thin plates (less than 4 mm). [3]

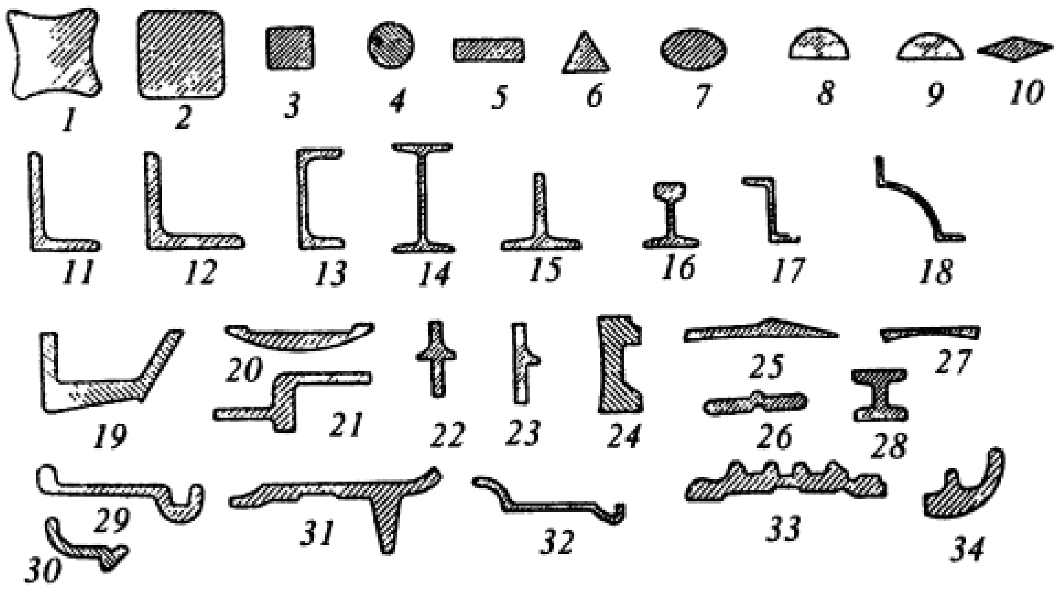

Figure 5 – Types of rolled sections: simple (1-10); shaped (11-17); special (18-34) [3]

2.2. Corrosion

Metals and alloys corrosion is their disintegration through the chemical reaction affected by the environment. All metals and alloys used in engineering corrode to a greater or lesser degree; only gold and platinum are corrosion-free in the normal conditions.

The examples of corrosion might be steel rusting under the influence of the atmosphere, erosion of ship's bottom, damage of chemical apparatus parts affected by the influence of salts, acids or alkalis and so on. Corrosion makes products partially or completely inoperability. At a rough estimate about 2% of all consumable metals and alloys are disintegrated annually due to corrosion. The damage caused by corrosion to the industry is exclusively great so that the corrosion protection is one of the most important objectives of the current engineering. The development of effective measures for the corrosion control, their proper and large-scale implementation in engineering should surpass the growth of caused damage.

Figure 6 – Destruction caused by corrosion

Steel corrodes in normal climate conditions even if not being electrically connected to other metal. This process is in line with the fundamentals of theory. Steel is inhomogeneous and contains sections which are slightly different in composition. On the line of crystallites, there are electrically dissimilar potential capacities and some sections being anode over others corrode in the case of two different metals.

All metals are thermodynamically-unstable and tend to react with the environment in order to form compounds such as oxides, carbonates, etc. These reactions are associated with the movement of electrons and called electrochemical reactions. The tendency for detachment of electrons varies from one metal to another and the more it is the more reactive metal is. [7]

2.2.1. Methods of Corrosion Protection

Steel and cast iron, constituting the principal part of all industrial metals and alloys, are rather strong susceptible to corrosion, for this reason, their corrosion protection calls for special attention. The producing of corrosion-resistant alloys (for example, high-chrome and chrome-nickel steel) is itself a method of corrosion control, at that the most effective. Stainless steel, as well as corrosion-resistant alloys of the non-ferrous metals, are the most valuable structural material, however, the use of such alloys is not always possible due to their high cost or for technical reasons. Because of these reasons, the following methods of the corrosion protection are used:

1) Metallic coatings
2) Chemical coatings
3) Cathode protection
4) Non-metallic coatings

The fourth group has got the most common appliance. It comprises 70% of all cases of metal protection against corrosion. Non-metallic coatings are painting, enamelling, japanning and lubrication. Their role as corrosion protection means is to isolate metal from the environment and to block the action of microelements on the metal surface. The choice of the paint and varnish coats is explained by the durability of this method of corrosion protection in the atmospheric conditions and by the simplicity of the process execution. The disadvantages of this protection method are the frangibility of coats and their burning at high temperatures. However, it is the most utilised method of metal products protection in the machinery and execution of steel structures. 75% of protection success depends on the relevant surface preparation and the reliability of application techniques. For this reason, the different experts develop so-called measures of the corrosion prevention. [7]

2.2.2. Preventive Measures

It is hard to deny that the corrosion prevention is the best remedy permitting to put an end to the corrosive attacks which cause enormous damage. Therefore, the more and more measures of corrosion control should be certainly developed at the design stage in the engineering departments in all industries. Many significant manufacturing destructions because of corrosion could have been avoided if appropriate measures had been taken.

It is possible to improve significantly the efficiency of the rationally worked out anticorrosive protection for constructions under any expectable conditions of the environment due to the optimal configuration, finish accuracy, preparations, texture and pre-processing of inner and outer surfaces, as well as when maintaining of their electrical and electrochemical stability. Further, considering that corrosion starts from the surface, it appears to be a strong case to set the appropriate precise parameters for the finish accuracy of the given surface at the design stage. [8]

One of those parameters is the obtaining of rounded angles and edges which provide a better uniform coating. Execution of this criteria in all fields related to the material protection from the external environment improves the efficiency and life time of coats, therefore, it became a mandatory practice and was included to many manuals and standards.

The most applicable documents were executed by the following famous Classification Societies:

- Det Norske Veritas - Germanischer Lloyd (DNV-GL)
- American Bureau of Shipping (ABS)
- Norsk Sokkels Konkuranseposisjon (NORSOK)
- International Organization for Standardization (ISO)

Every society such as these has its own standard for the specific products regulating the admissible characteristics and deviance of a construction from the established norms:

- DNV-OS-C401
- NORSOK M-501
- EN ISO 8501
- EN ISO 12944

2.3. Rounding of Sharp Edges

Fulfilling the requirements of life duration and reliability of products is the fundamental condition in manufacturing and operation of machines. Defects of edges, being a particular case of surface damages, are stress-concentrators and expedite the destruction of parts themselves and friction surfaces. It is known that the edge of a detail or any other item is a result of the intersection of two surfaces and theoretically must be a line. The contour of this line is defined by the shape and relative positioning of the intersecting surfaces. The actual edge is not always a line, but a transitional surface of irregular and geometric shape, the dimensions of which depend among others on the roughness of surfaces composing it.

The edge processing of parts is an important process of the production cycle comprising the following operations: edges preparation with random radii, dimensional rounding, deburring and decontamination, etc. Figure 7 illustrates the evaluation of the applied protective coat on the steel surface pursuant to the international standard ISO 12944 [9].

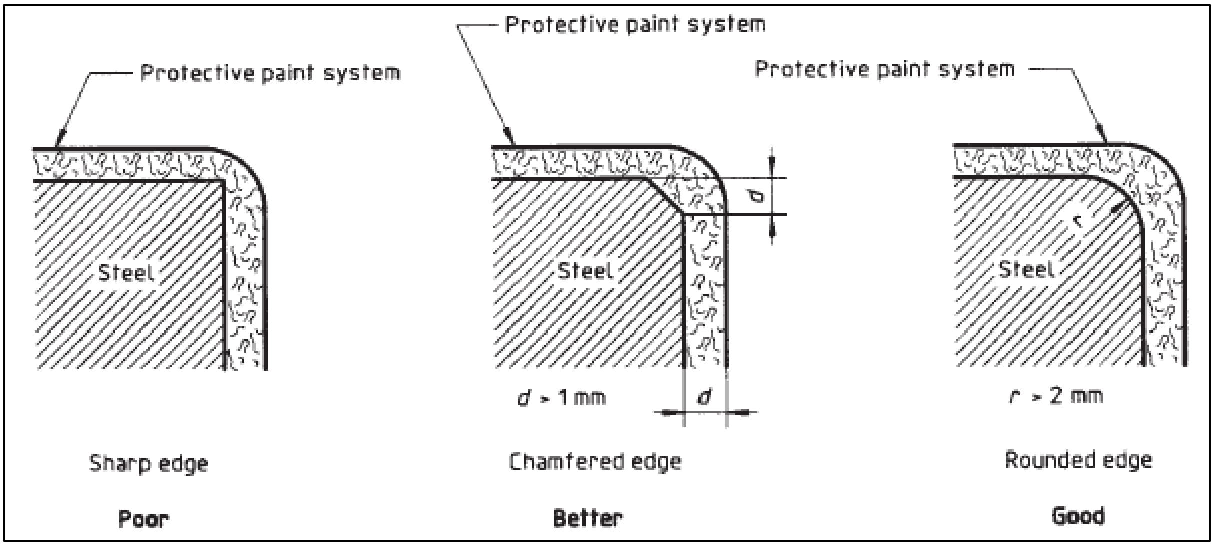

Figure 7 – Surface protection layer in case of three different edge preparation states [9]

According to the research conducted in 2007 by the Korean scientists of Hyundai Heavy Industries [10], the efficiency of edges preparation of different products when applying anticorrosive protective coats was proved. Figure 8 displays the cross-section cut of metal and paint coats with the thickness of 240, 310 and 440 micrometres. Depending on the form, the difference of coating thickness is observed that in the unprocessed case in the edge area could draw up 40% of the required layer. It proves once again the efficiency of the sharp edges preparation by means of beveling or rounding.

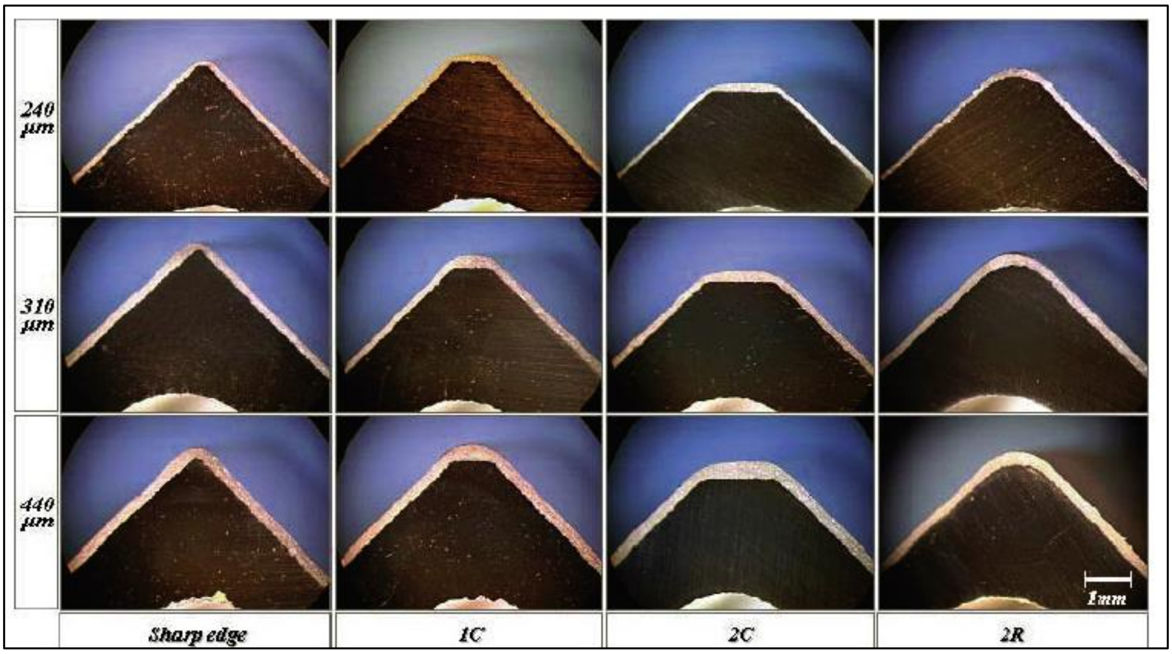

Figure 8 – Protective coating thickness dependence on the type of edge preparation: 1) Sharp edge; 2) 135^o angle chamfer; 3) 150^o angle chamfer; 4) 2 mm rounded edge; [10]

In the case with beveling the thickness of the applied layer in the edge area had exceeded the thickness of flat coat, thus it was decided to conduct the second stage of the research in order to detect the most appropriate method of sharp edge processing. The results showed that the uniform painting is more effective than local thickening. In Figure 9 we can observe that when using the edge rounding with radii more than 2 mm, the most uniform surface is attained. When using the beveling, the stressed state of the protective layer appears which in turn makes the edge area more fragile.

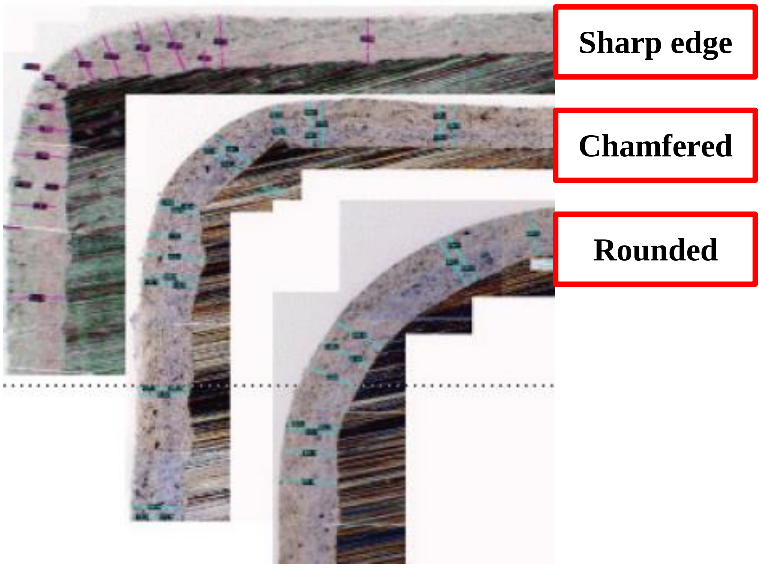

Figure 9 – The difference in coating uniformity [10]

Edge rounding of metal constructions is so vexed and multifunctional task that the scientific societies and certain production units are permanently dealing with it. The manufacturing technicians are developing particular solutions for their extremely specialised problems. The implementation of this stage of processing procedure is associated with solving of production, social and economic problems as a whole.

For the moment, there are about 120 worked out finishing and stripping methods reflecting the importance and actual continuity of this technology class as well as the complexity of problem solving. Based on the physic-chemical affection to materials while processing, the existent methods of trimming, finishing and edge cleaning of parts, could be divisible into five groups: mechanical, chemico-mechanical, chemical, electrochemical and physical. In diversity of technologies it is possible to make good use in production only very few methods which couldn’t form the secondary liquids, don’t change the geometry, don’t cause the structural changes of the parts material, provide the ecological cleanness, permit to mechanise and automate the processing, as well as to ensure the reliability and life time of products in operation. [11]

The methods of deburring and sharp edge rounding are divided into dominant and nominal. The dominant methods include universal cutting methods characterised by the high efficiency and wide usage in the machine building. Dimensionless processing methods, such as rumbling, vibroabrasive processing, extrusion, electrochemical, mechanical and manual methods with the application of different instruments as brushes, scrapers, milling cutters are mainly used for trimming and rounding of edges. Dimensional processing of edges in the process of manufacturing dominated by the small-batch, multiproduct, continuously updated production represents a challenging task. To solve it, it is required to optimise the numerous interdependent factors characterising parts, equipment and production process. [12]

2.4. Involved Company [13]

MARKETEX
OFFSHORE CONSTRUCTIONS
BLRT GRUPP

Figure 10 – Company logo

Marketex Offshore Constructions (hereafter MOC) offers large-sized complex solutions and every day faces a great variety of challenges mentioned in previous chapters, thus, to maintain its competitive position a constant development is required for both technology solutions and equipment. So, drawing attention to the economical and statistical indicators related to the process of rounding of sharp edges, the attention was drawn to this issue. Covering the theoretical basis of rounding of sharp edges, it is worth also to get acquainted with MOC because further the problem will be considered and analysed relying on the requirements and needs of the given enterprise.

The company was founded during the restructuring of BLRT Marketex OÜ and is a daughter company of BLRT Grupp which is one of the biggest industrial holdings in the Baltic Sea region. The predecessor of BLRT Grupp - the Russo-Baltic Shipbuilding Yard - was one of the most advanced shipyards on the Baltic Sea when it was established in 1912. Today, incorporating five shipyards, BLRT Grupp offers complete range of quality services on all phases of a vessel's lifespan, from designing to recycling. The holding also maintains a leading position in the production of metal solutions, metal and gas trading, as well as offers transport and port services.

Figure 11 – Geographical location of BLRT Grupp AS

Having the modern equipment and perfect location with direct access to the sea, Marketex Offshore Constructions is capable of handling even very large and highly complex projects. MOC has a solid experience in production ranging from small equipment to large and complex projects. The company focuses strongly on energy markets, which have high requirements and standards of quality, providing a stringent control of quality and lead times.

The team of qualified specialists establishes direct communication with customers and maintains it throughout the entire project. It helps the company to form a thorough understanding of the customers' needs and to ensure the development of close cooperation. Company employees work together to achieve a single objective – to provide the customers with the most optimal solution of the assigned task. The team pulls together at all management levels – from welders and project managers to top management.

2.4.1. Production Capacities

For the moment, Marketex Offshore Constructions is an experienced offshore equipment producer for oil and gas industry, notably the structures from carbon steel (including HARDOX and WELDOX), stainless steel and aluminium. Hydraulics, electrical equipment, piping, outfitting and lining are offered within the framework of the turnkey projects. Over 400 of our highly skilled workers, including subcontracted personnel, are working in 7 production workshops with a total area of more than 28 500 m^2. All welders have certificates of major Classification Societies and/or DVS (German Welding Society). All workshops are equipped with a wide range of welding equipment.

Figure 12 – BLRT Grupp AS production base in Tallinn, Estonia

2.4.2. Projects

OFFSHORE:

- Tree Cranes
- Derrick Towers
- Trolleys
- Elevators
- Mouseholes
- Compensation Devices
- Sea Fixing Devices

INDUSTIRAL:

- Ship Loaders and Unloaders
- Ship to Shore Cranes
- Reclaimers
- Stackers
- Container Cranes
- On-board Cranes
- Gantry Cranes

The market of offshore oil and gas equipment is one of the most high-technology market sectors because here the implementation process of advanced developments and solutions is constantly active, which permits oil companies to produce oil from more and more deep layers of earth surfaces. And this, in its turn, demands special skills from engineering and manufacturing companies.

Between 2007 and 2015 the company has successfully completed more than 100 different projects for oil and gas markets weighing from 1 ton up to 200 tons. Its activities include the manufacturing of large-sized lifting and handling units in cooperation with the biggest providers of crane and port equipment, thus, the company proved itself as a trustworthy partner on the market of industrial equipment. Also, MOC is engaged in installation of industrial equipment for the leaders of the pulp, paper and wood handling industries. Wood handling conveyors with mechanical installations, debarking drums and other equipment have been delivered to Metso Paper OY, Andritz OY and Raumaster OY for mounting at pulp and paper mills in different countries of Europe, Asia, South America, and Africa.

Figure 13 – Main partners logos

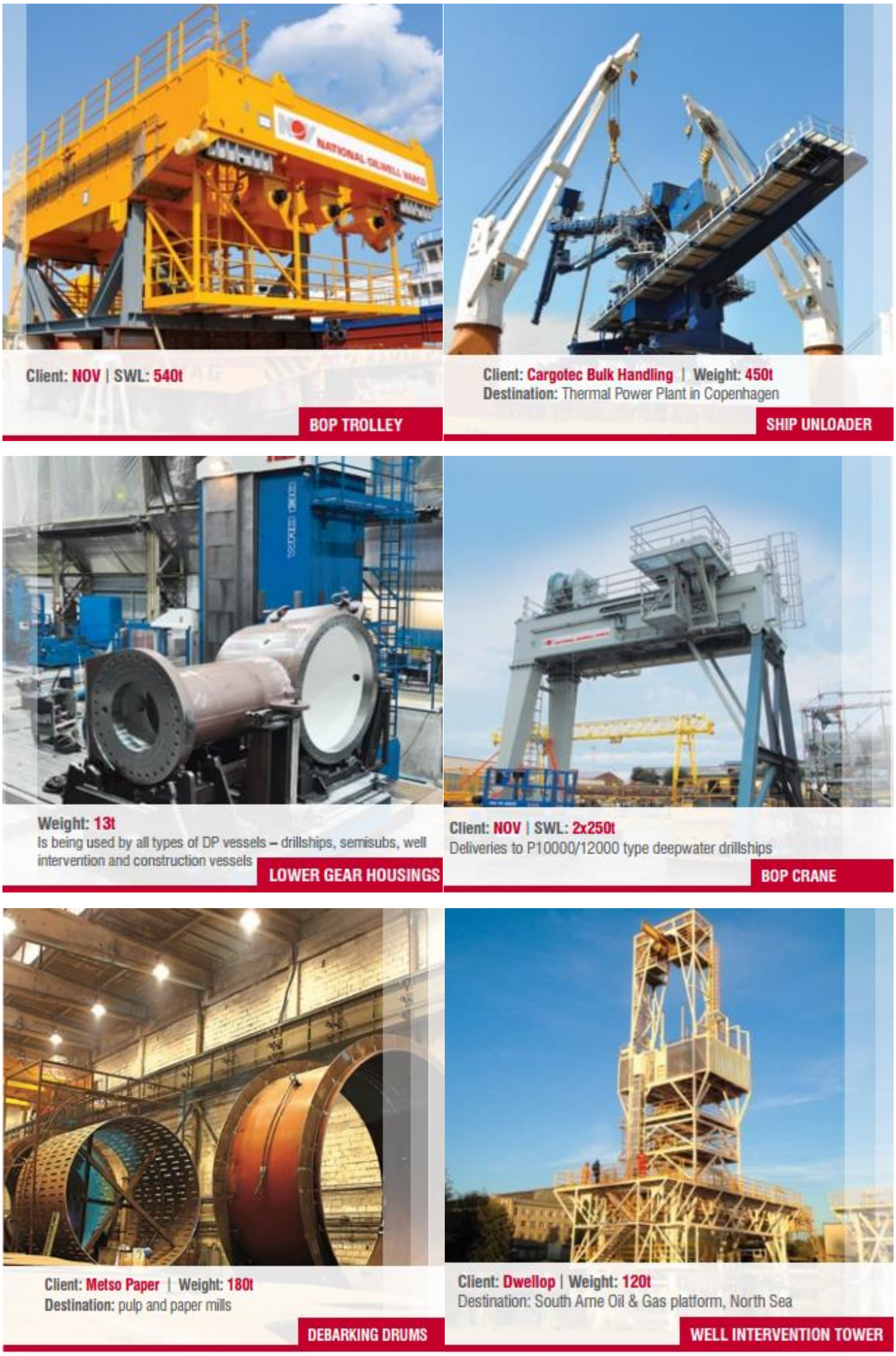

Figure 14 – Examples of produced equipment

3. MARKET RESEARCH

The requirements of machine building and offshore equipment dictate very strict rules, and complexity and large sizes of structures imply the use of almost all range of rolled metal products and the mandatory application of corrosion protection. For this reason, the key factors of decision making for the stated range of problems are:

- Controlled dimensional rounding of edges with the radii of not less than 2 mm
- Applicability to various types of profile
- Processing of large and complex parts

The first item excludes the use of processing methods of sharp edges such as finish grinding, line grinding and filing bright. These methods are non-dimensional and the quality of their execution is overly dependent on the human factor.

The second and the third clause identified strict frameworks upon which it was found that the majority of units or machines are specifically designed for processing of sheet metal of almost any size and form. Furthermore, this type of equipment is relatively well-developed both in terms of technological and economic factors.

The logical step was to focus on solutions for the range of rolled profiles. At the moment, such equipment is derived from obtaining of chamfers and bevels by mechanical means which in their turn are based on milling methods. The unique special projects produced for the end customer are the exceptions. Depending on the degree of automation there are manual, mechanised and automated equipment.

The market niche of milling equipment is not monopolised and each type is produced by various companies. So, in the course of further research this equipment will be grouped and will have average technical-and-economical indexes. The unique projects will be presented separately. Main data resources were obtained from the sites of manufacturing companies, equipment exhibitions and direct communication with vendors. The subsequent chapter focuses on the review of received information and assessment of applied technologies.

3.1. Available Equipment

3.1.1. Special Milling Heads

To resolve the task of rounding of sharp edges by means of mechanical methods standard milling head has been replaced by the newly designed special holders in which the cutting inserts of appropriate form are installed. These heads are suitable for use on practically any milling machine and have customizable configurations for both rounding of sharp edges and beveling. The holder could be installed on the collar (collet chuck) to obtain the longer head if the machining in hard-to-reach places is required.

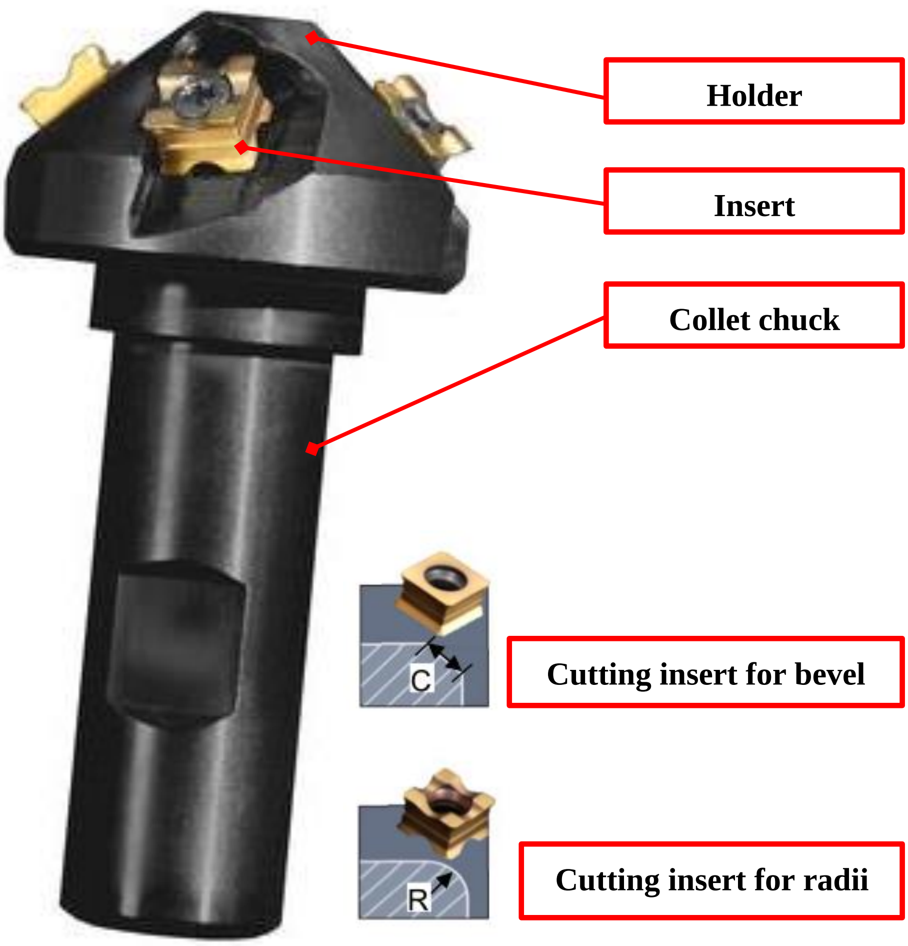

Figure 15 – Milling head assembly TMW4 by GERIMA [14]

Parameters:

- Radii – from 2 to 20 mm
- Chamfer – from 0.2 to 15 mm
- Number of cutting insers – from 2 to 8
- Holder diameter – from 14 to 90 mm
- Angular velocity – from 1200 to 12000 Rounds Per Minute

3.1.2. Stationary Beveling Machines

The stationary beveling machines allow processing of curved parts (the minimum radius R=500 mm). The beveling is carried out either by the solid milling cutters made of rapid steel or by the set of composite holder with cutting carbide plates. There are two types of beveling machines: with the movement of milling head and workpiece. The machines with the movement of workpiece have much simpler construction. In particular, angles change of processed bevel is normally achieved by the inclination of milling head relative to the machine bed. This type of equipment was designed for the production process of welding bevel, but using various milling heads it is possible to carry out the rounding of sharp edges.

Figure 16 – Stationary beveling machine by MMB600 by GERIMA [15]

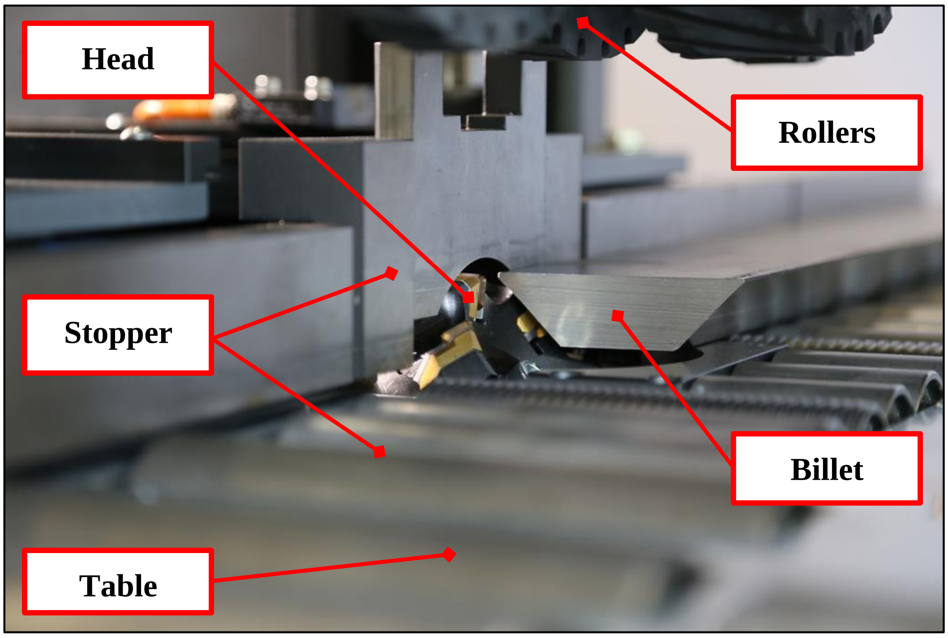

Figure 17 – Basic components in case of stationary beveling

Principle of operation

The worker places by hand the billet on the table. The rolls press the part and move it horizontally along the retaining plate (stopper). The milling head that handles face and edges of the part is in a specially provided hole.

Purpose

The machine is intended to produce bevels by means of the milling process using the face mill, but when using the special head with replaceable cutting inserts, it is possible to carry out the rounding of sharp edge of a part.

Capacity

The equipment is designed for processing of sheet-metal billet with the thickness from 3 to 100 millimetres. Workpiece dimensions depend on the size of the table, up to one meter in width and up to 6 meters in length. Restricted processing of the outer edges of profiles up to 100 millimetres in height is theoretically possible when using technical equipment. Additional trimming is not required after processing because the mechanical method provides a high-quality level of the edge's surface. The rotation speed of mill and pressing rollers is automatically controlled. It permits to process just one edge in a single pass.

3.1.3. Mobile Beveling Machine

Mobile beveling machines duplicate the stationary ones in the processing technologies differing only in the means of movement. Earlier models were moved manually by the worker, but with the development of the pressing technology of machine to part, the processing became practically automatic. The mobile machines are irreplaceable at the processing of long-length parts (rectilinear or curved) in the cases when the enterprise does not have the stationary beveling machines or when processing of a part is inexpedient on them. As in the case of stationary model, the rounding of sharp edges is achieved by means of special milling head.

Figure 18 – Mobile beveling machine MULTIEDGE by GBC [16]

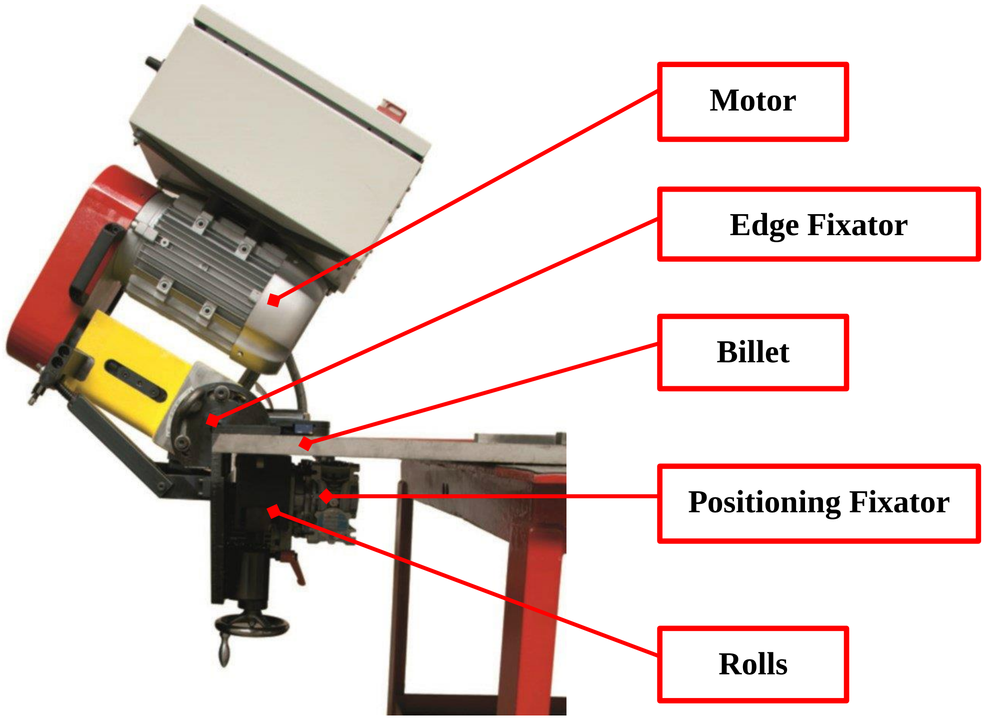

Figure 19 – Basic components in case of mobile beveling [16]

Principle of operation

The machine is installed by the worker to the processed surface of billet. Due to automatic feed system with the adjustable speed the machine is fixed on the edge of detail without operator's intervention or the use of lifting mechanisms. By means of guiding rollers, the machine moves along the edge of detail. Revolving head with replaceable cutting inserts is used as cutting instrument for rounding of sharp edges. It is installed in a special hole between clamps.

Purpose

The machine is intended to produce bevels by means of the milling process using the face mill, but when using a special head, it is possible to carry out rounding of sharp edge of part.

Capacity

The equipment is designed for processing of sheet metal with the thickness from 7 to 70 millimetres. The length and width of a billet is not defined. Restricted processing of the outer edge of profiles from 200 millimetres in width is theoretically possible. Additional trimming is not required after processing because the mechanical method provides a high-quality level of the edge's surface. The rotation speed of the mill and pressing rollers is automatically controlled. It permits to process just one edge in a single pass.

3.1.4. Hand Operated Beveling Machines

It is a hand-operated mechanised tool which represents the standard angle grinders equipped by special milling heads with replaceable cutting carbide inserts. They are very convenient at processing of complex parts with various holes, cut-outs, curved sides, but they require certain skills from workers.

Figure 20 – Hand operated beveling machine TKA500 by TRUMPF [17]

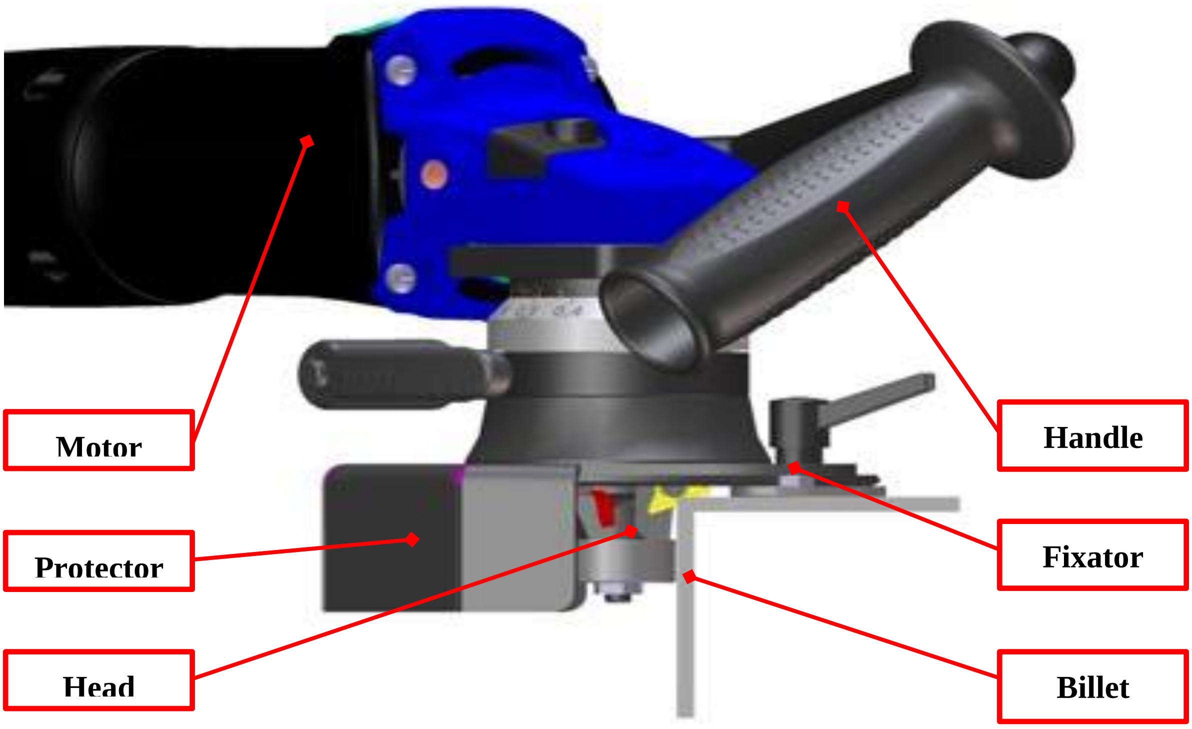

Figure 21 – Basic components in case of hand operated beveling [17]

Principle of operation

Depending on specifications of metal the worker adjusts the required parameters: the distance of remote plate, the cutting depth of a plate and spindle speed. The machine moving along the edge is carried out manually by the operator. Special head with replaceable cutting inserts or end mill with profiled section are used as cutting instruments.

Purpose

The machine is specifically designed for the rounding of sharp edges of any metal profile and allows executing bevels by means of the replaceable inserts.

Capacity

The flexibility of this type of equipment makes it irreplaceable in the field of machine building and construction of large-sized metal structures. The operation is limited by the distance to the electric grid and by the thermal overload (for every 15 minutes of operation 15 minutes of rest are required). The additional trimming is not required after processing because the mechanical method provides a high-quality level of the edge's surface. The rotation speed of the mill and press rollers is automatically controlled. It permits to process just one edge in a single pass.

3.1.5. Smooth Rolling Technology

The equipment offered by HEXA executes rounding of edges in automatic mode using their continuous mechanical smooth rolling by means of press rollers. The comparison in efficiency of various methods of finishing in most cases is for the benefit of smooth rolling, particularly in the heavy engineering of individual and limited production with the use of universal metal-cutting equipment. Peculiar to the heavy engineering, the completion of finish operations on turning, boring, planning and boring-facing machines connected with the restricted distribution of grinding machines that are suitable for processing of extra-large parts, offers exciting possibilities for the smooth rolling. But also for the cases when it is possible to use grinding, the smooth rolling can replace it successfully, if the machine provides the required accuracy. At that, overlapping of operations offers a significant reduction of the production cycle.

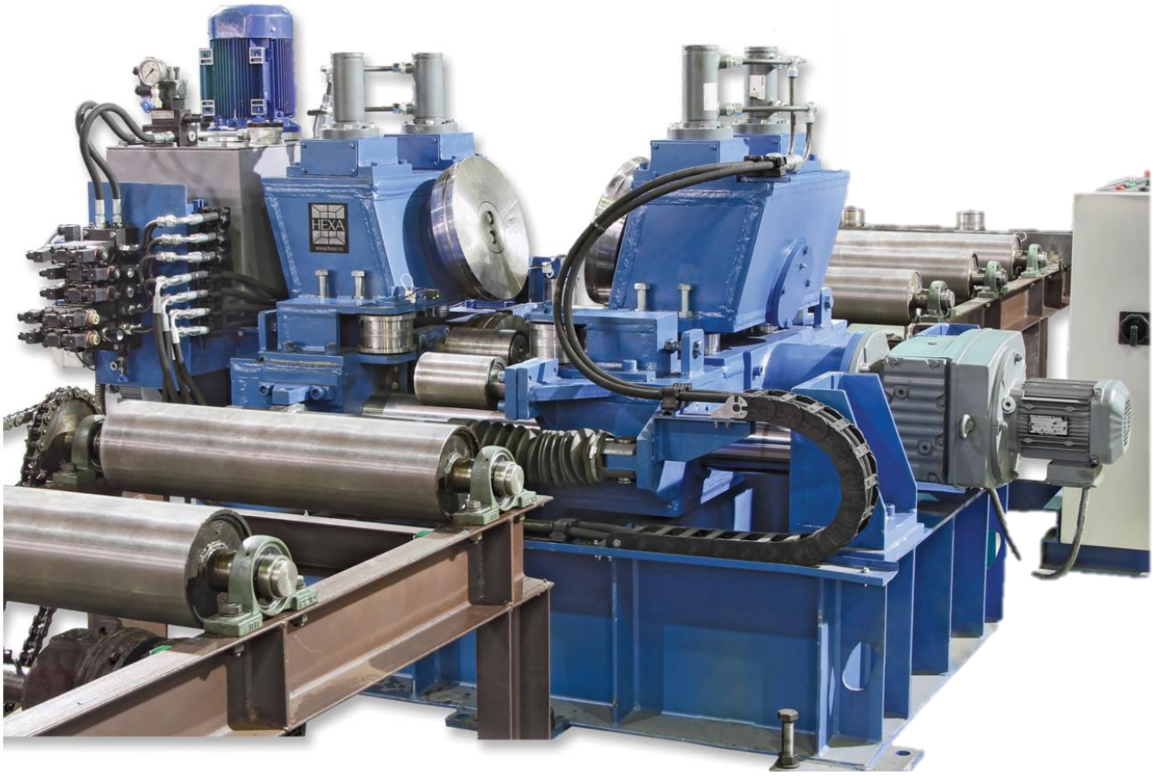

Figure 22 – Machine base on smooth rolling technology by HEXA [18]

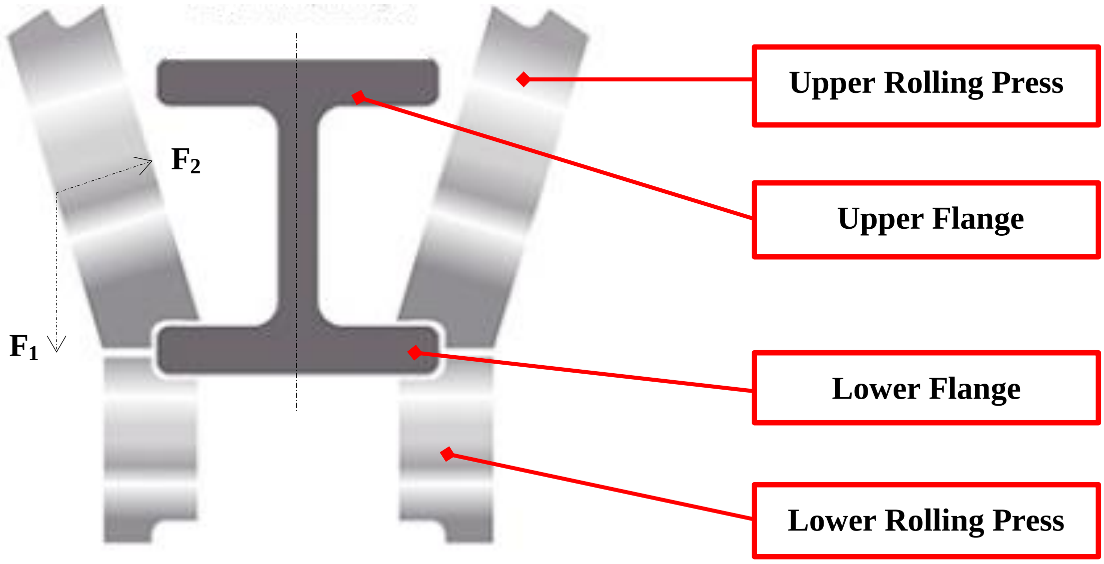

Figure 23 – Smooth rolling schematics [18]

Smooth rolling

The smooth rolling is a plastic deformation of the part's surface layer by the smooth polished roller of high hardness. At the same time as a result of the bearing of buckles remained from previous processing, a new surface profile with the reduced height of surface micro roughness is created. The difference of finishing by means of smooth rolling from various methods of cutting lies in the fact that the surface metal layer is plastically deformed, but not destroyed and removed. The plastic working is followed by metal hardening, consequently, by the increase of hardening of the surface layer and occurrence of compressing residual voltage in it.

Principle of operation

Billet is placed by the operator to the feeding conveyor which directs it to the processing unit of the smooth rolling machine. The first level of the unit represents the system of guide rollers having the role of direction and adjustment of further moving of billet. In the second level press rollers are involved in the operation, being the main machine mechanism. The cold plastic working of edges and further moving of billet to the receiving conveyor are carried out by means of these rollers. If necessary to process top of billet, chain tilters turn over the part and start the backward of the process. The overall operation is carried out on the free-standing control panel by the operator.

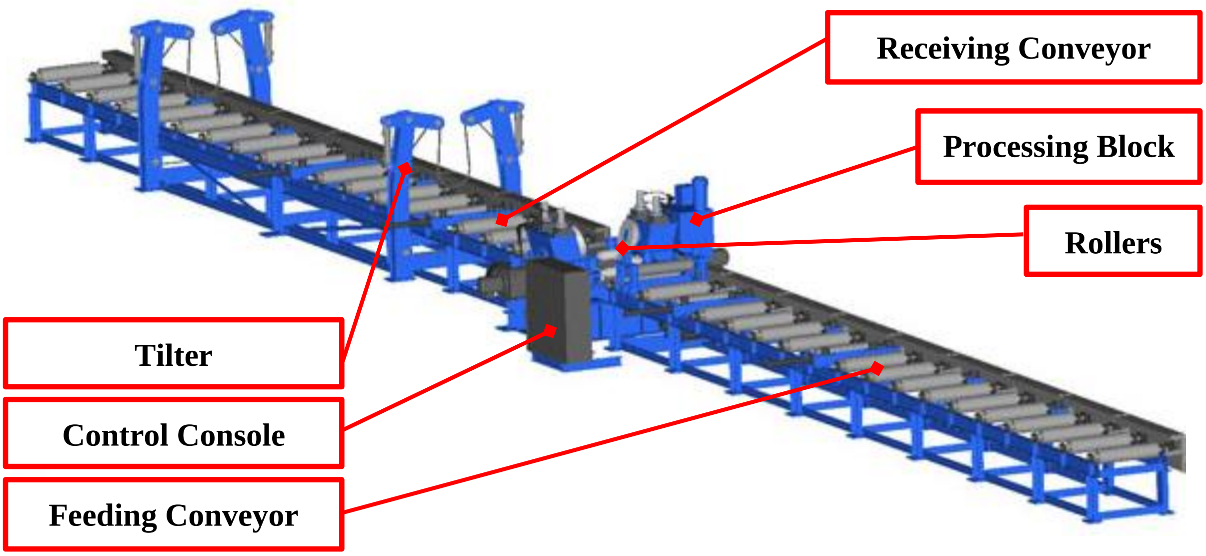

Figure 24 – Rolling technology line OK2DL-50-500 by HEXA [18]

Purpose

The smooth rolling machine is intended for rounding of edges of an I-beam in automatic or manual mode. 4 of 8 edges of an I-beam are processed in a single pass (bottom flange), after that the 180 degree rotation (turning) and the backward processing of another 4 edges take place. The machine is capable to process sheet metal in a single pass.

Capacity

The process automation and service staff minimising allow the use of this equipment on a continuous flow basis at large-scale. The simple design and easy replacement of parts significantly simplify the use and increase the life time of machine. The geometry and location of press rollers limit the dimensions and forms of workpieces.

- Profile – Beams or Plates
- Minimal width of billet – 200 mm
- Maximal width of billet – 700 mm
- Length – from 2000 to 12000 mm
- Minimal thickness of flange – 8 mm
- Maximal thickness of flange – 50 mm

3.1.6. Abrasive Processing Technology

Unique stationary machine by GECAM is based on abrasive method, at which grinding tool or billet shuttle together with the rotary motion. The equipment is designed for the processing of surfaces of a considerable length that exceeds the height of grinding tool. It implies the use of additional accessories, required for establishing the processing line. Each detail is produced according to the customer's requirements.

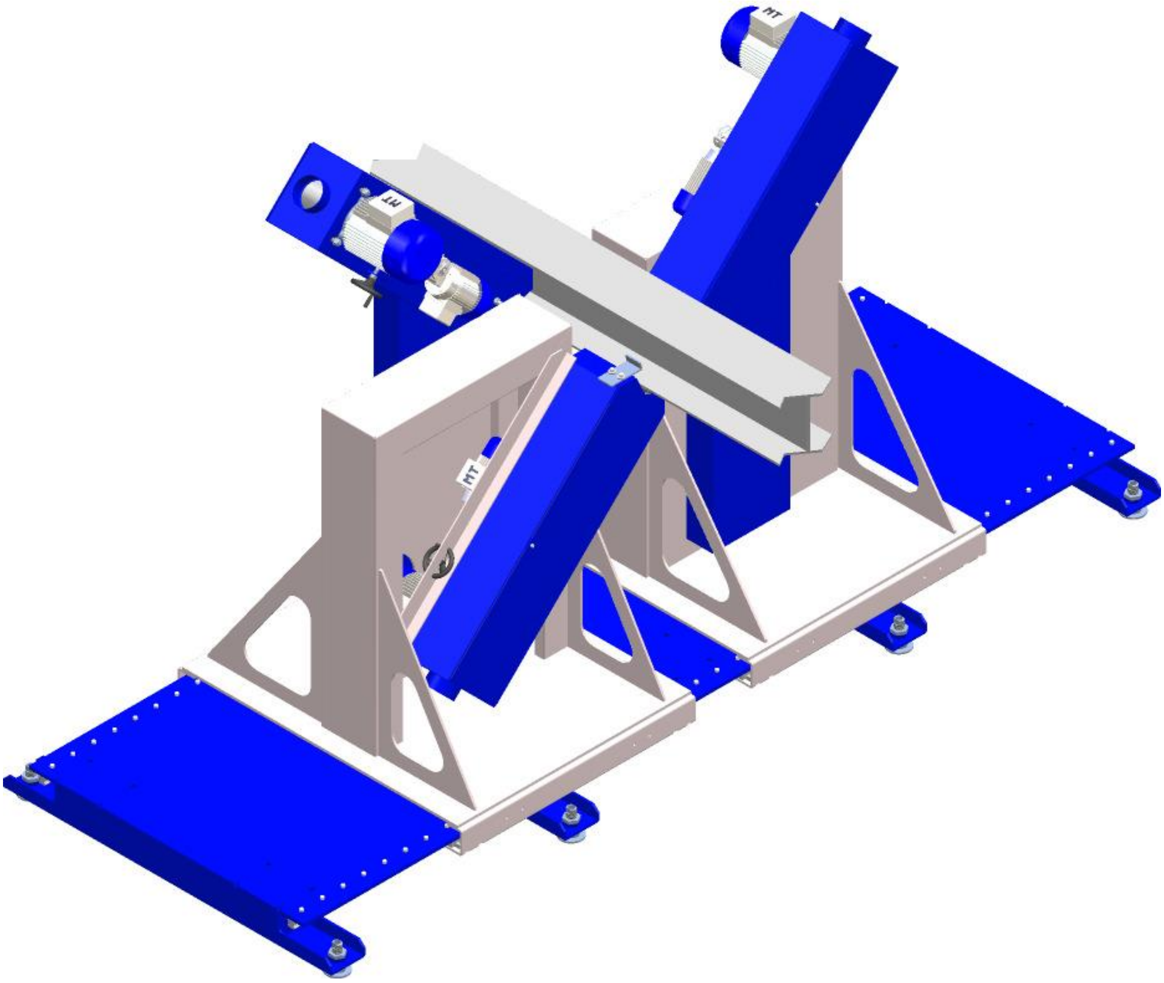

Figure 25 – Machine based on abrasive technology by GECAM [19]

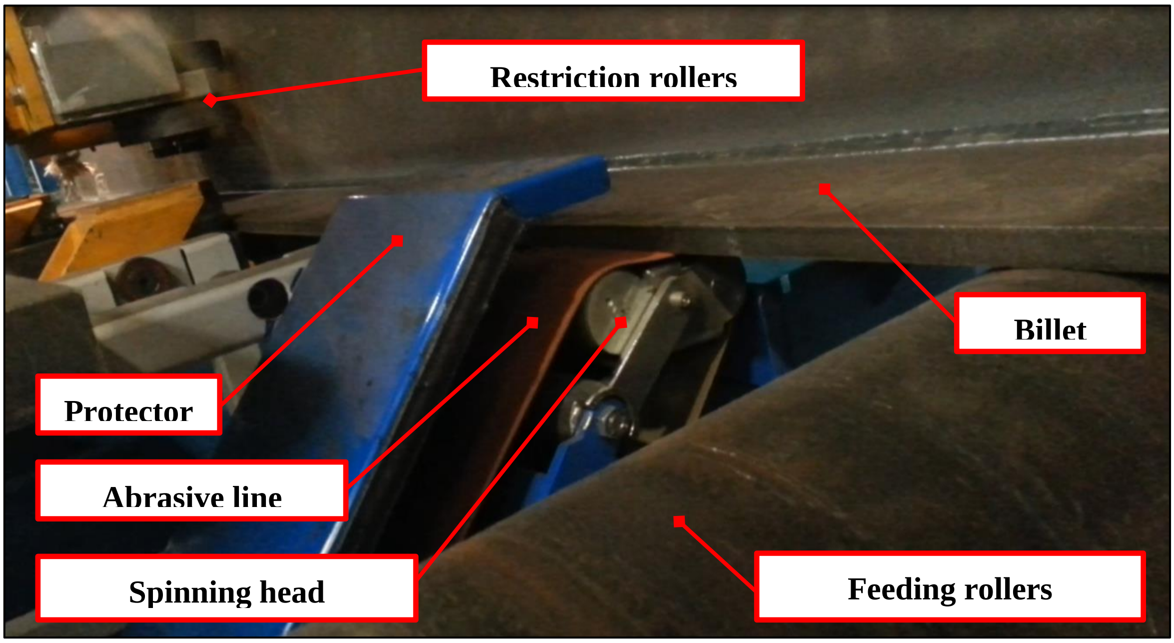

Figure 26 – Basic components of the abrasive system by GECAM [19]

Abrasive processing

The abrasive processing is the finishing execution by cutting that is carried out by means of abrasive grains in the form of monocrystals, polycrystals or their chips. As opposed to the metal blade processing there is no continuous cutting edge, and it consists of a huge number of separated cutting elements (abrasive grains) bounded among themselves by the bond. Therefore, the working ability of the abrasive tool is defined not only by the material and size of cutting abrasive grain but also with the composition and amount of the bond and by the structure (disposition of abrasive grains and pores in the tool).

Principle of operation

The billet is placed by the operator to the feeding conveyor which directs it to the processing unit of the rolling machine. Restriction rollers position the part so that it reaches the operating zone of the processing units. The rounding of sharp edges is carried out by means of abrasive tape fixed on the rotating head. If necessary, after the processing of the part’s bottom the turning devices roll it over and the process occurs in the opposite direction.

Purpose

This equipment is specially designed for I-beams processing. It is possible to round 4 of 8 sharp edges in a single pass, after that the 180 degree rotation (turning) and the backward processing of another 4 edges takes place. The improved machine is capable to process U-channels and sheet metal.

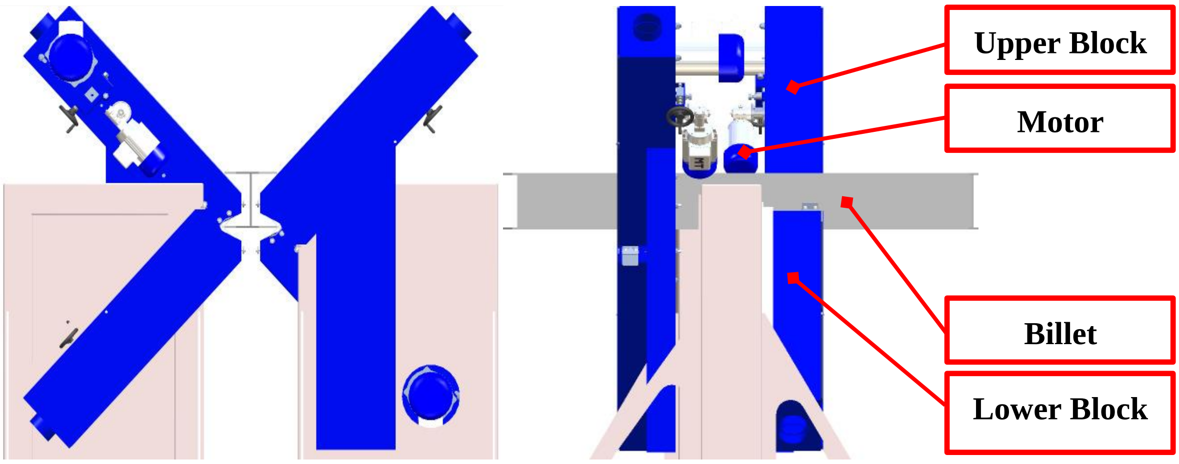

Figure 27 – Front and side view of the abrasive system by GECAM [19]

Capacity

The process automation and service staff minimising allow the use of this equipment on a continuous flow basis at large-scale. In that particular case, the restriction is the geometry of the processing unit which includes abrasive tape, rotating head and tape-feed device. Admissible forms and dimensions:

- Profile – Angle Bars, Beams, Channel, Plates
- Minimal width of billet – 200 mm
- Minima height of billet – 200 mm
- Length – from 2000 to 12000 mm
- Minimal thickness of billet – 8 mm

3.1.7. Parameters

Figure 28 – Table of work parameters of the studied equipment [15] [16] [17] [18] [19]

Processing Method	Milling			Rolling	Abrasive
Type	Stationary	Mobile	Hand	Technology line	Technology line
Processable profile	Plate / Beam / Channel	Plate / Beam / Channel	No restrictions	Plate / Beam	No restrictions
Minimal height (mm)	3	No restrictions	No restrictions	200	200
Maximal height (mm)	100	No restrictions	No restrictions	700	1000
Minimal thickness (mm)	3	7	3	8	8
Maximal thickness (mm)	100	70	No restrictions	50	No restrictions
Minimal width (mm)	No restrictions	200	No restrictions	200	200
Maximal width (mm)	1000	No restrictions	No restrictions	700	No restrictions
Minimal length (mm)	100	500	No restrictions	2000	1000
Maximal length (mm)	6000	No restrictions	No restrictions	12000	12000
Processing speed of one edge (m/min)	2	1	1	12	5
Processable edges	Outer	Outer	No restrictions	No restrictions	No restrictions
Number of edges at one pass	1	1	1	4	4
Price (€)	10 000 - 15 000	7000 - 9000	2000 - 4000	190 000	180 000
Size (W x L x H mm)	1000 x 1200 x 1600	800 x 800 x 1500	250 x 300 x 450	26000 x 3000 x 2000	28000 x 1500 x 2000

3.2. Overview

Milling

Machining allows obtaining the highest accuracy and quality of the edge's surface. After mechanical cutting on the edge's surface there are no burrs which could be the reason of defects occurrence. However, the machining has a series of restrictions:

- Low efficiency
- The processing complexity of edges of large-sized parts
- The processing complexity of non-perfect parts
- The necessity of parts turning

Rolling

The efficiency of the line based on the smooth rolling of metal is the best of all equipment available on the market. The processing restrictions of the form (sheets and I-beams) and minimum dimensions (both height and width) reduce strongly the workability of the given machine as universal equipment.

The material reinforcement (hardening) at the cold plastic working of edges is positioned as the technology advantage by the producer. In fact, the hardening has a range of inadmissible parameters restricting the use of this technology in the machine building:

- Reduction of the metal density

At the hardening of metal, its density reduces. The reason is that the plastic working leads to the violation of the anatomic array order, increasing defects density and micro pores formation.

- Residual stress

The outer hardened layer tends to be expanded, but the inner layers hold it – consequently, the compressive residual stress appears in the hardened layer.

Abrasive

In this particular case, the abrasive processing benefits from the speed and possibility of the continuous processing of large-sized parts with different profile sections. However, the use of such processing line becomes difficult due to the following factors:

- Edge rounding by means of the abrasive methods is environmentally unfriendly:
    - Nose
    - Vibration
    - Emission of large amount of dust
- Problem of waste recycling
- Don't guarantee the exact dimension of an obtained edge to the requirements.
- The chipping of abrasive occurs at the abrasive cutting (that has a negative impact to the surface condition when painting).
- The abrasive chips penetrate into the surface layer of metal which plasticises because of the intensive thermal overload.
- The imbedded chips have sharp edges.

3.3. Analysis

All above mentioned methods have their strengths and weaknesses and the choice of technology depends on the workpieces and their volumes (see Figure 28), as well as particular conditions of manufacturing. It is important to estimate, what of the examined technologies is the most applicable on the production site and will provide a necessary accuracy, being at the same time the cheapest possible.

The most utilised equipment for rounding in the Baltic countries is a hand-operated beveling machine which allows processing any surfaces at any time of production cycle. Like all represented options, this type has two grave disadvantages – low efficiency and dependence on the human factor. Stationary and mobile beveling machines solve partially this problem, but impose restrictions on dimension and form of a billet.

The processing lines by methods of smooth rolling and abrasive benefit in the context of efficiency and easy handling, due to the successfully implemented conveyor system with the use of turning devices. Nevertheless, their applicability is not considered as possible first of all because of the hardening in case of smooth rolling and imbedding of abrasive chips to metal in case of abrasive technology. The following restriction is the minimum dimensions of a billet.

When considering possibilities of processed range of products in whole, there are gaps within the dimension range of profiles. The profile of 200 mm and above could be processed on the lines, but the profile of less than 100 mm can be processed on the stationary beveling machine (at the proper additional preparations). The range of sizes, starting from 100 mm and ending to 200 mm, represents the problem which is possible to be solved only by means of a low-production hand-operated beveling machine.

Taking into consideration both the equipment restrictions and positive aspects obtained as a result of the in-depth review and analysis of the technology market, arises the justified decision of the development of a machine capable to process a range of profile products of the required dimensions. The components that should be pointed and used in the further development of the equipment:

- Milling heads for rounding (holder, cutting insert, collet chuck)

Represent the most successful solution for rounding of sharp edges at which the required dimensions and quality are achieved.

- Position control system of a billet on the rolling processing line

Mechanical system able to direct the part to processed place without the use of additional sensors (electrical, optical etc.).

- Conveyor system

By means of in-line processing it is possible to achieve the productivity improvement.

- Position of cutting tools in abrasive line

The processing of 4 edges in a single pass increases significantly the efficiency. The processing of all possible edges should be ideally executed (8 edges of an I-beam) that will allow to get rid of the turning of parts!

4. SALES RESEARCH [20]

ELME Metall, being a part of BLRT Grupp, handles purchase and sales of metal of any form. This fact played a great positive role due to the chance of review and collection of the required information. The statistical analysis is based on sales of the range of profile products of carbon steel covering the five-year period and includes the following items:

- Nomenclature
- Material
- Size
- Volume

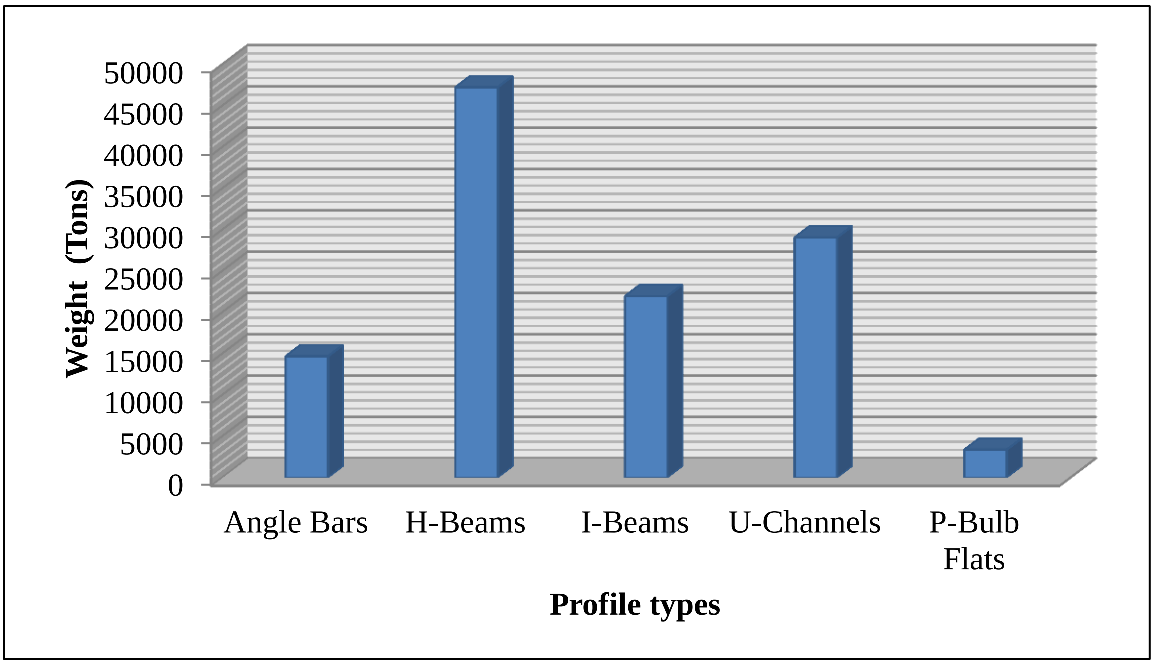

Figure 29 – Sales of different profile types in Tons

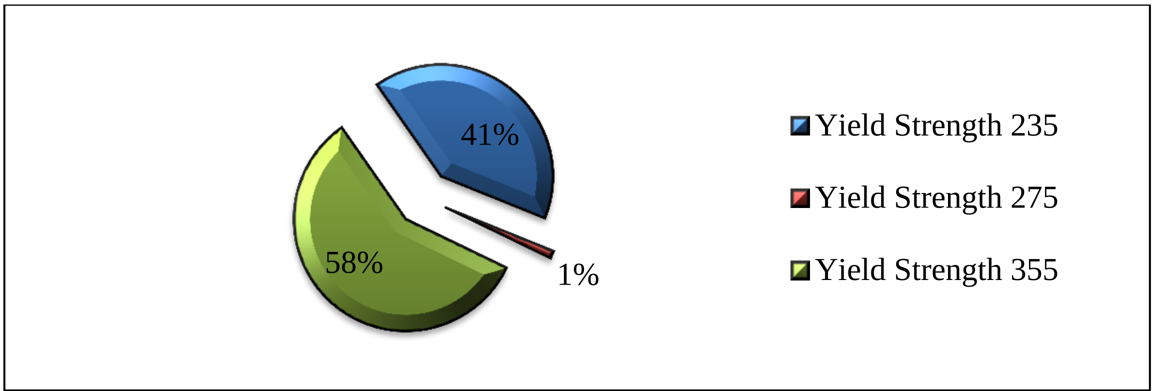

Figure 30 – Sales of different material grades in Percentage

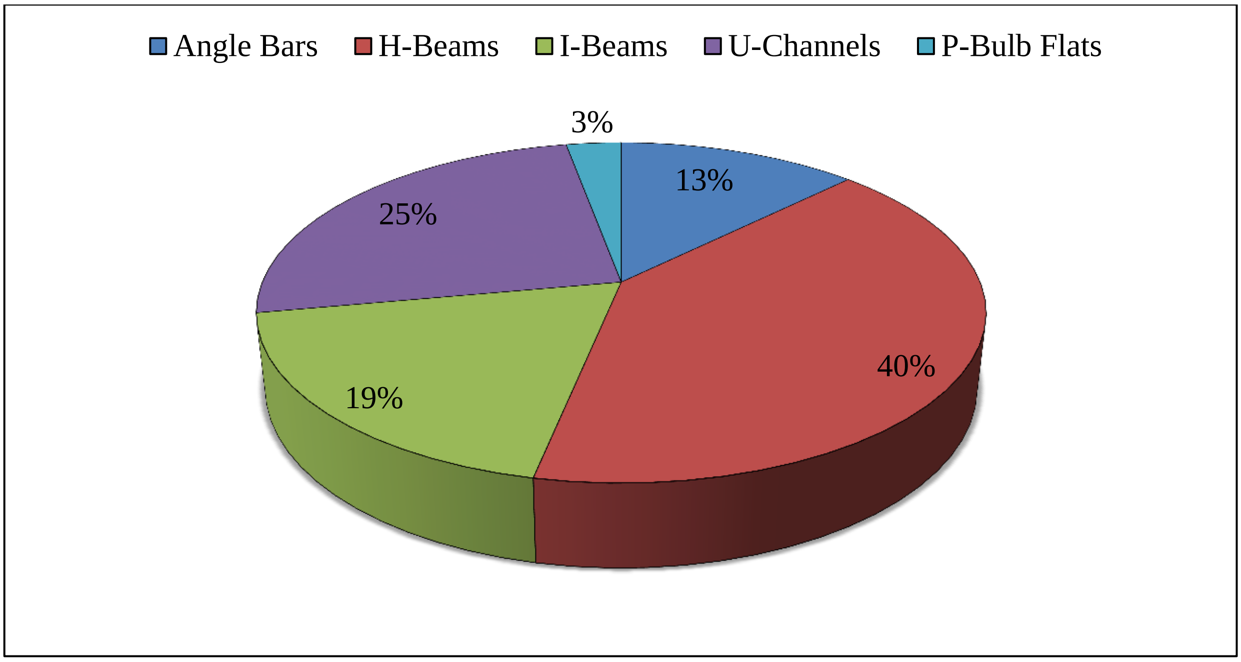

Figure 31 – Sales of different profile types in Percentage

The equipment market analysis showed that offered methods and technologies are suitable for various kinds of profiles of different sizes. This fact is caused by various restrictions, including components of machines. To that end, it becomes clear that the development of a machine adapted for processing of the full range of products does not appear feasible. Therefore, it is worth to stay focused on that range of forms and sizes which represents the unsolved problem, namely on the range of profiles of less than 200 mm.

The Diagrams 1 and 3 show the sales of various profiles. The largest volumes belong to I-beams (59%), U-channels (25%) come next, angles (13%) and bulb bars (3%). The geometry of the last type means the rounded edges after rolling, for this reason, the bulb bars were excluded of the further analysis. For determining the current dimensional frameworks each type of profile will be examined separately.

4.1. Statistics

4.1.1. Angle Bars

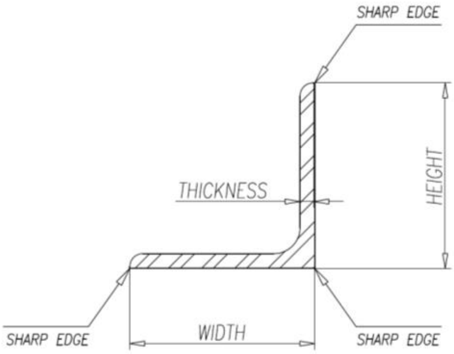

Figure 32 – Angle bar cross-section

Parameters:

- Number of sharp edges – 3 outer
- Minimal thickness – 4 mm
- Maximal thickness – 35 mm

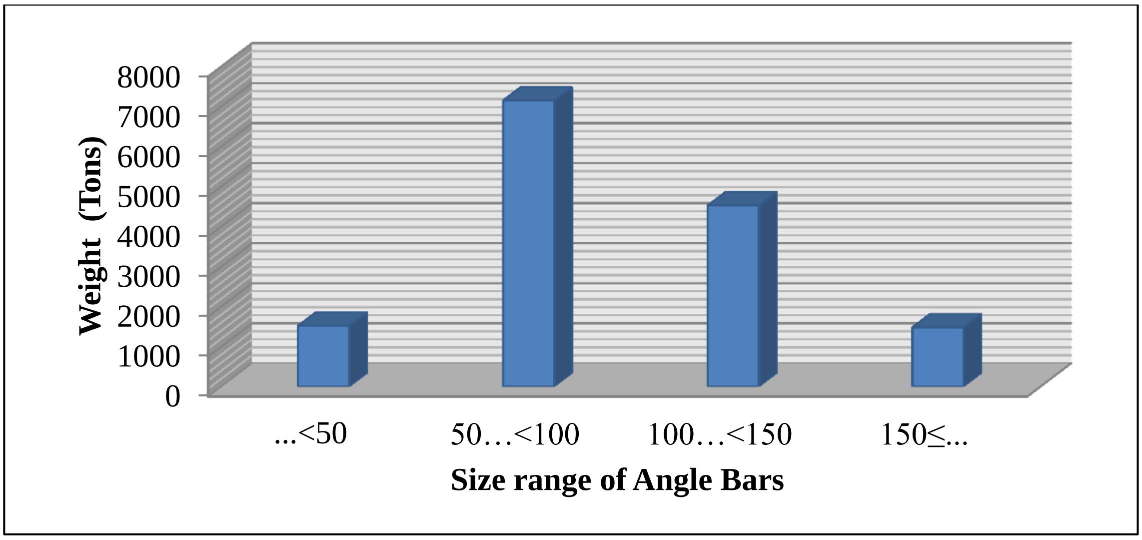

Figure 33 – Sizes and weight of sold angle bars

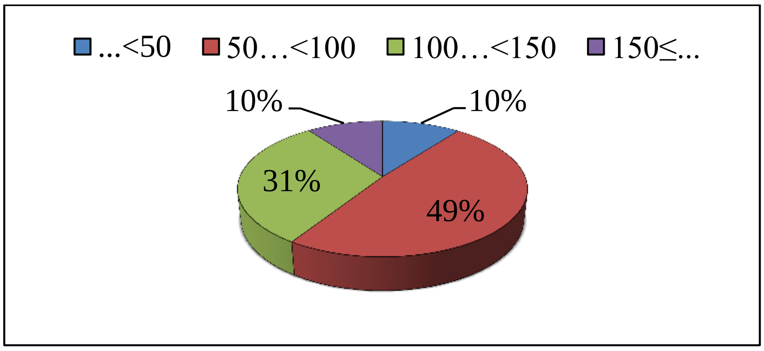

Figure 34 – Size range of sold angle bars in percentage

4.1.2. H-Type Beams

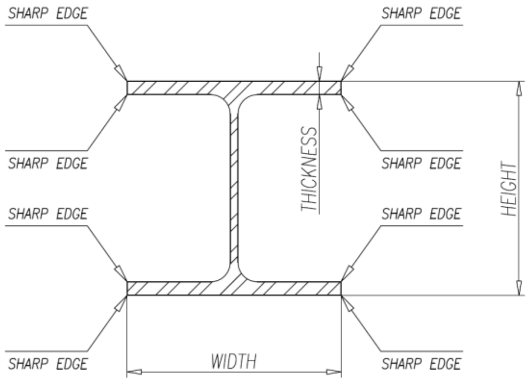

Figure 35 – H-Beam cross section

Parameters:

- Number of sharp edges – 4 outer and 4 inner
- Minimal thickness – 8 mm
- Maximal thickness – 40 mm

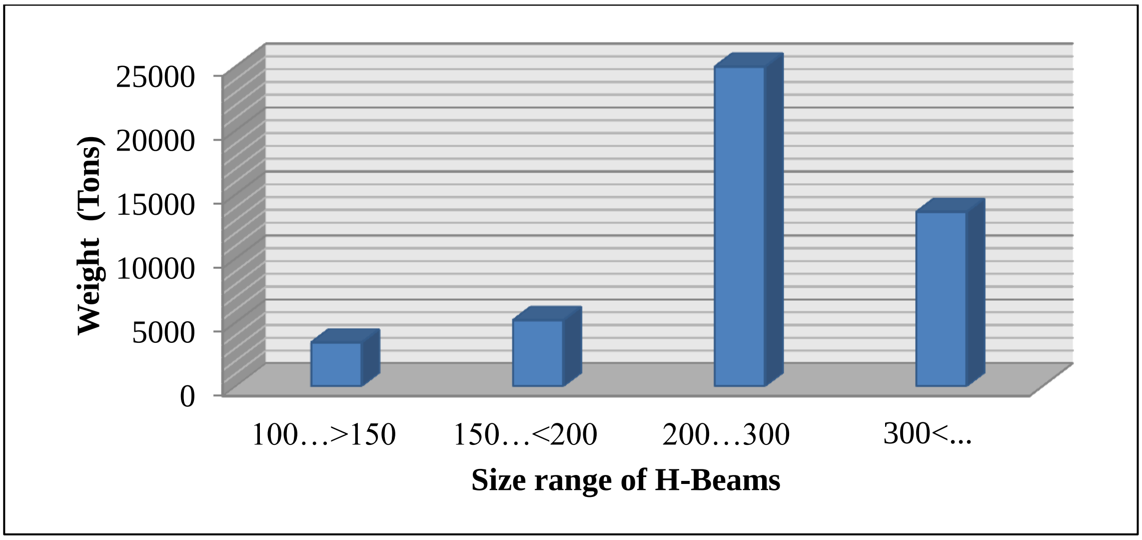

Figure 36 – Sizes and weight of sold H-Beams

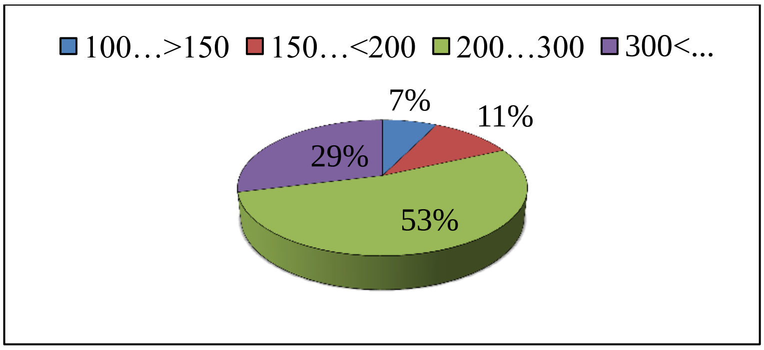

Figure 37 – Size range of sold H-Beams in percentage

4.1.3. I-Type Beams

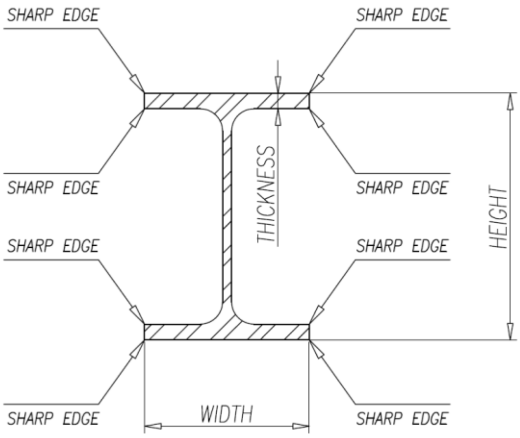

Figure 38 – I-Beam cross-section

Parameters:

- Number of sharp edges – 4 outer and 4 inner
- Minimal thickness – 4 mm
- Maximal thickness – 32 mm

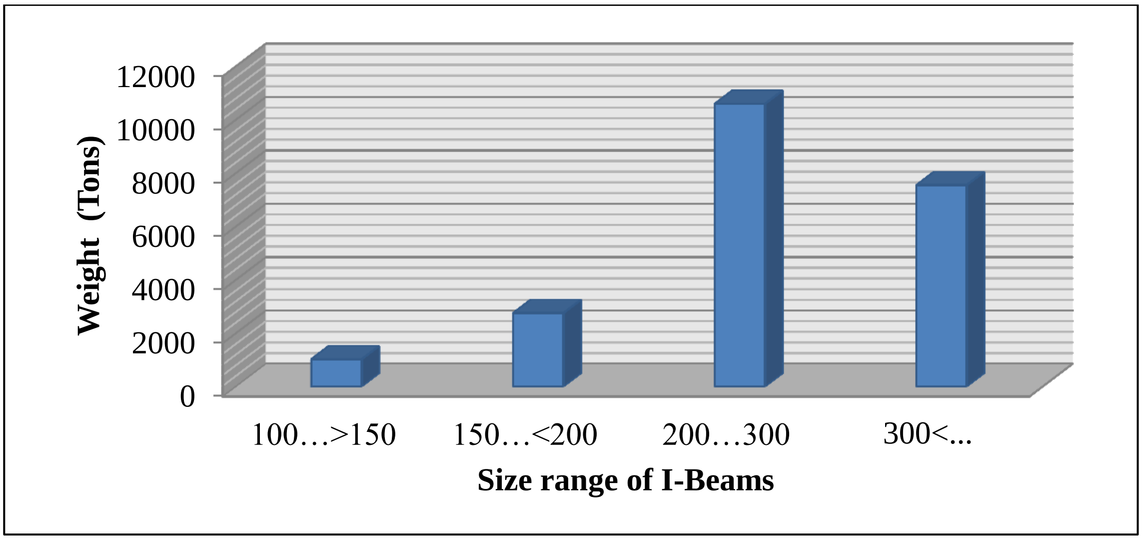

Figure 39 – Sizes and weight of sold I-Beams

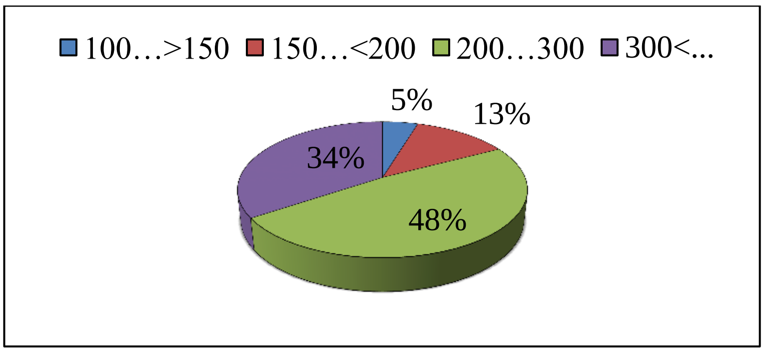

Figure 40 – Size range of sold I-Beams in percentage

4.1.4. U-Type Channels

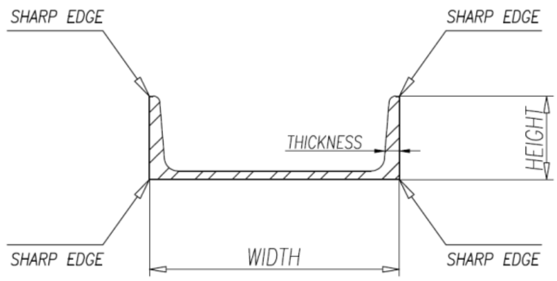

Figure 41 – U-Channel cross-section

Parameters:

- Number of sharp edges – 4 outer
- Minimal thickness – 7 mm
- Maximal thickness – 18 mm

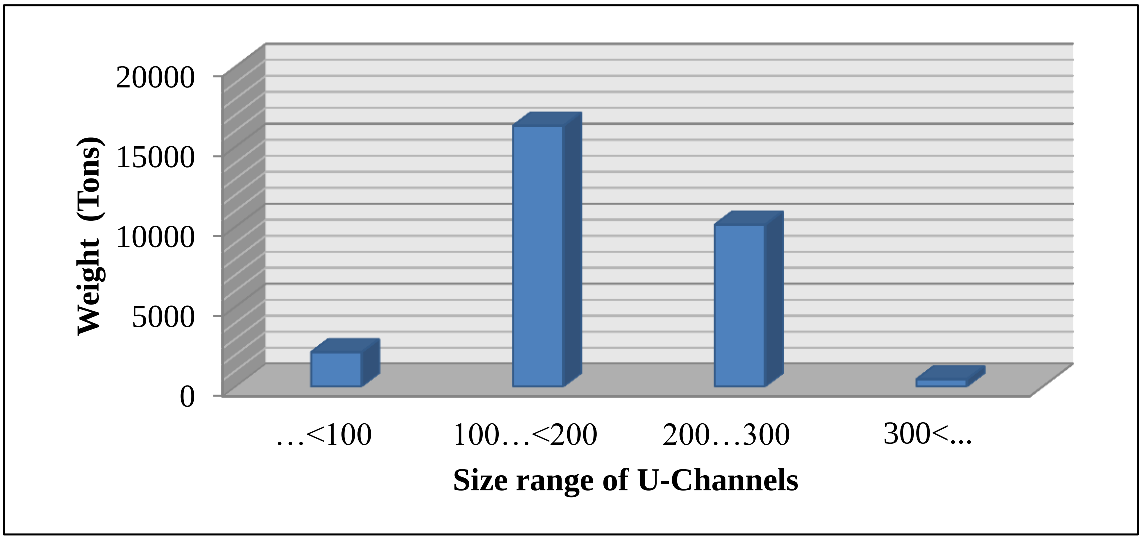

Figure 42 – Sizes and weight of sold U-Channels

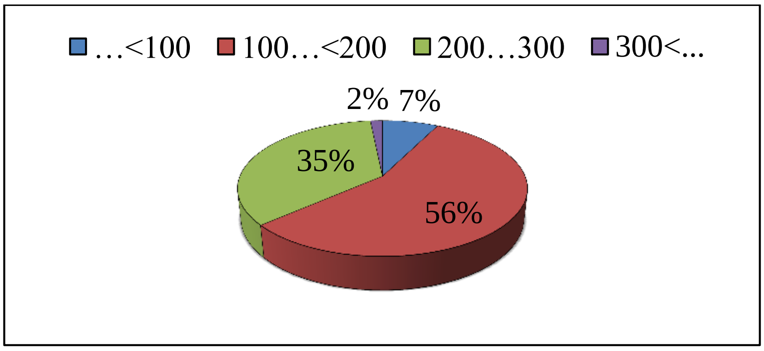

Figure 43 – Size range of sold U-Channels in percentage

4.2. Results

The statistical analysis covering the five-year period, from 2010 until 2015, showed the overall total of 116276 tons of sold profiles of carbon steel. The figure is substantial enough to designate the problem seriousness of rounding of sharp edges. Each type of profile, bulb bars excluded, has from 3 to 8 edges demanding full or partial processing before the use in the machine building. At the same time, 40% (45 000 tons) of used sizes fall exactly to the dead range of equipment (height or width is less than 200 mm). This fact confirms finally the necessity of new equipment development intended for rounding of sharp edges.

The realisation of the universal equipment suitable for processing all of the rolled metal products, at the current level of the technological development and production opportunities, appears elusive. One of the possible solutions is the restriction of dimensions of workpieces, at which the variance of the profile forms remains. Due to the low sales level, the following parameters should be neglected: angles with a flange of less than 50 mm, U-channels of less than 50 mm and above 300 mm. Taking into account these characteristics, the range of sizes covering 80% of sales (90 000 tons) was worked out:

- **Angle Bars (equal and unequal):**
    - Minimal width or height – 50 mm
    - Maximal width or height – 250 mm
- **Beams (HEA; HEB; IPE; IPN etc.):**
    - Minimal width or height – 80 mm
    - Maximal width or height – 300 mm
- **Channels (UPE; UPN etc.):**
    - Minimal width or height – 50 mm
    - Maximal width or height – 300 mm
- **Common:**
    - Minimal thickness – 4 mm
    - Maximal thickness – 35 mm

5. CONCEPTUAL DESIGN

5.1. Functional Interrelationship

A broad and comprehensive analysis of the problem provided an excellent base for the further phase of the development of the required equipment. Selection of conveyor feed type and milling processing method itself formed the idea of setting up a production line with a full or partial automation of operations. Mechanisms of this type are relatively complex systems consisting of several parts or assemblies that have one function or more. Therefore each node should be considered as a separate mechanism with own requirements and limitations.

According to the selected methodology the conceptual design stage starts with setting functional interrelationship of the system with a clear and easily reproduced relationship between inputs and outputs. Firstly, a broad definition of the system is represented by the "Black Box" block diagram showing only main function with initial inputs and final outputs of the system.

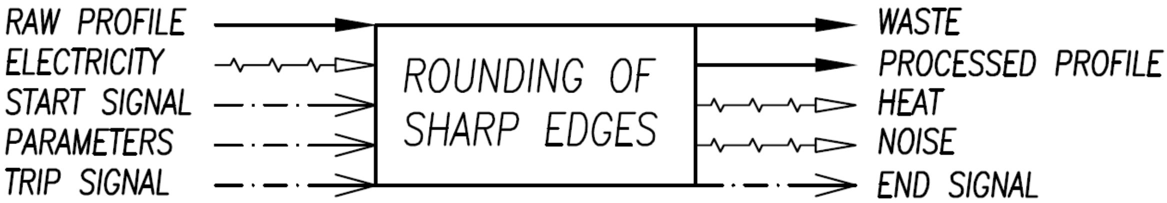

Figure 44 – Conversion of material, energy and signals in case of rounding of sharp edges

Figure 44 shows "Black Box" block diagram of the system for rounding of sharp edges. The material (unprocessed profile) is being fed into the processing block where rounding is being done. The system is powered by electricity (chosen as an example of power source) and operated by such primary signals as sense of the movement (trip signal), detail parameters and engagement of the system (start signal). As a result of proper functioning, processed profiles with some quantity of waste are the material outputs. The undesirable flows include heat and noise. The completion of cycle is performed by ending signal.

The next stage consists of establishing a function structure by breaking down an overall function into sub functions which describe the process of rounding of sharp edges. Inputs and outputs (material, energy, signals) are staying the same as in the first stage, however their conversion inside the system is also expanded. Functions and their connections represent only what should be done, but not how!

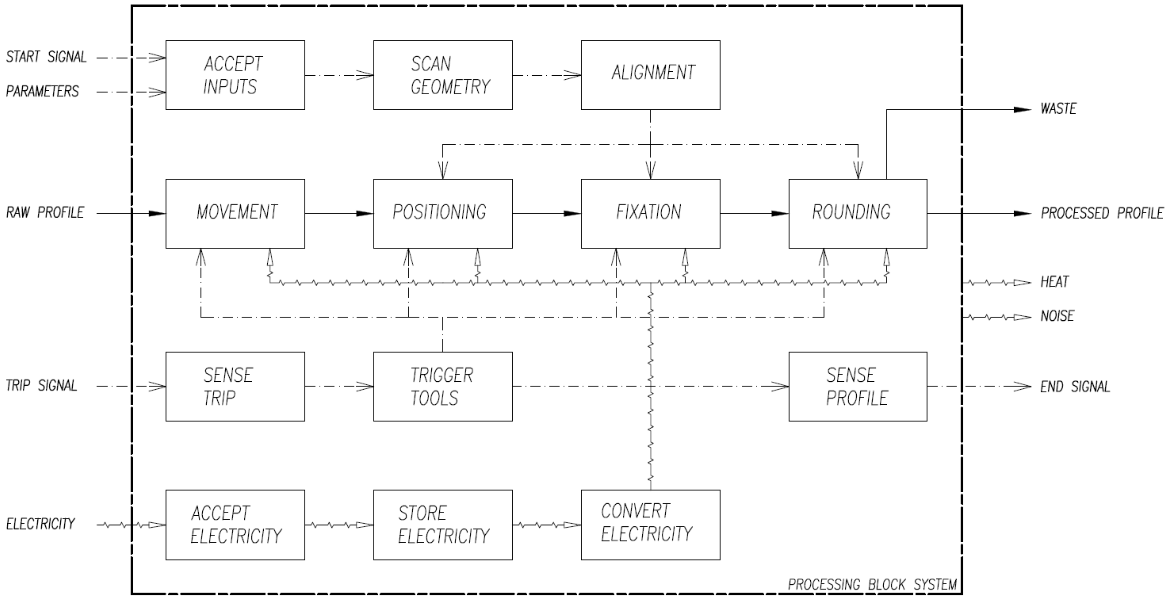

Figure 45 – Function structure diagram of rounding of sharp edges

In order to get a processed profile are needed next basic sub functions: movement inside the system, positioning of the detail into the right place, correct fixation of the cutting mechanisms on the material and rounding of sharp edges. Each sub function consumes different kinetic energy volumes which are converted from the stored electricity (or other energy sources).

Since material can have different features (type, grade, size etc.) some parameters and engagement of the mechanisms are entered manually. The system analyses inputs and scans geometry to correct and align the position of tools. Movement of the material triggers the start of the inside processes. The cycle ends when detail is not present in the system.

Sub functions proposed in the function structure diagram on Figure 45 belong to different kind of engineering fields; therefore it is crucial to set requirements, specific parameters and boundaries for the purpose of creating the design specification. Analysis of the structure led to deeper understanding of connections between blocks ultimately resulting in combination of sub functions due to the similar kinematics. The next chapter is intended for expanding sub functions into more detailed level needed for embodiment of concepts.

5.2. General Technology

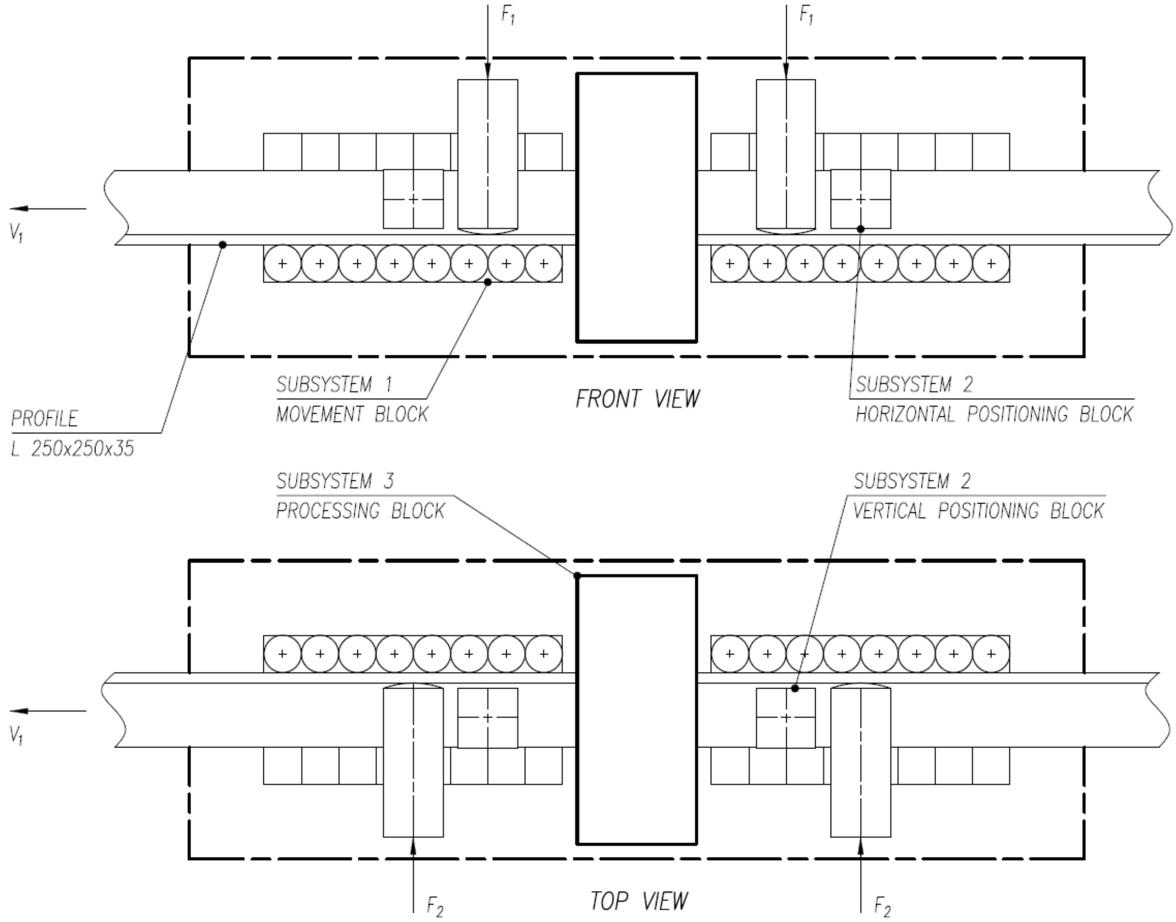

Figure 46 – General arrangement of sub function blocks

Rounding of sharp edges on profiles on Figure 46 represented as a production line. The feed of the material (Angle bar 250x250x35 chosen as illustration) into the system is done by conveyors which are not shown on the scheme. The process is performed by three blocks:

- The first subsystem is intended for movement of the profile inside the system. For the illustration purpose it is shown as rotating rollers giving desired linear speed V_1
- The second subsystem is divided into horizontal and vertical parts that keep the profile on the correct position by applied forces F_1 and F_2
- The third subsystem is processing block where the rounding is being done

5.2.1. Movement and Positioning Technology

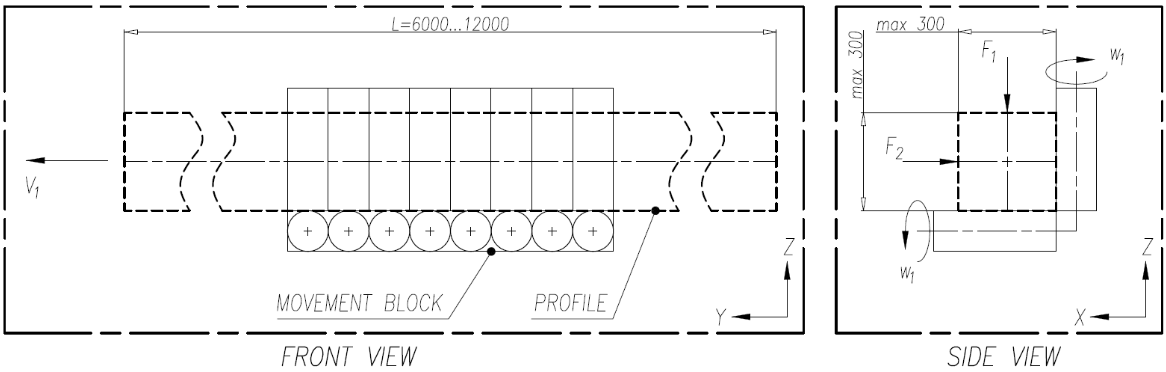

Figure 47 – Movement and Positioning technology scheme

First parameters had been defined in previous chapters, namely maximal height, width and length which are shown on Figure 47. On the side view of the scheme positioning of the profile with maximal dimensions (300x300x12000 mm) is being performed by forces F_1 and F_2. Angular speed W_1 of the rollers keeps linear feed rate of the detail. However, processing profiles can have different sections with different points where forces should be applied. For that purpose additional measurements are shown on Figure 48.

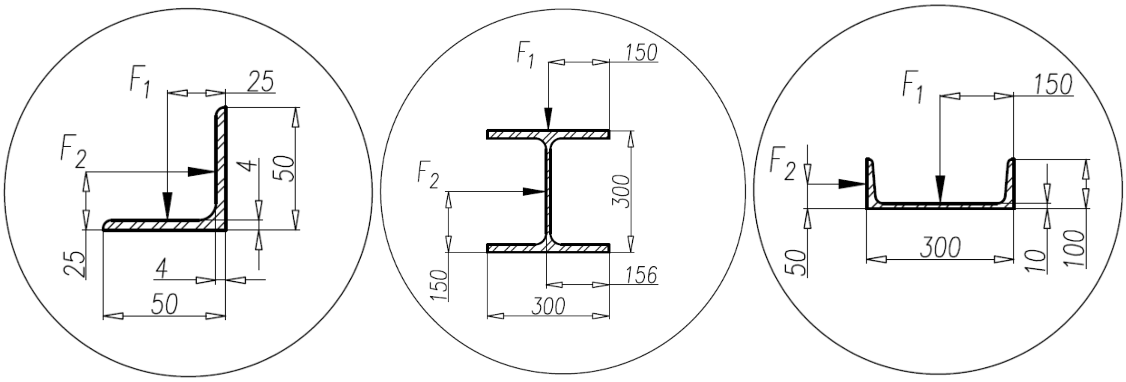

Figure 48 – Position of forces in utmost cases

Minimal dimensions are set in case of Angle Bar 50x50x4, maximal in case of beam HEA 300 and channel UPN 300. Height is defined by Z value and width is defined by X value.

Vertical Positioning Block (F_1):

- X_{min} = 25 mm
- X_{max} = 150 mm
- Z_{min} = 4 mm
- Z_{max} = 300 mm

Horizontal Positioning Block (F_2):

- X_{min} = 4 mm
- X_{max} = 300 mm
- Z_{min} = 25 mm
- Z_{max} = 150 mm

5.2.2. Movement and Positioning Parameters

Technology scheme of movement and positioning creates a proper kinematic system, which also has to be quantitatively defined by different factors. Figure 49 illustrates simplified kinematic scheme of the first and second subsystem.

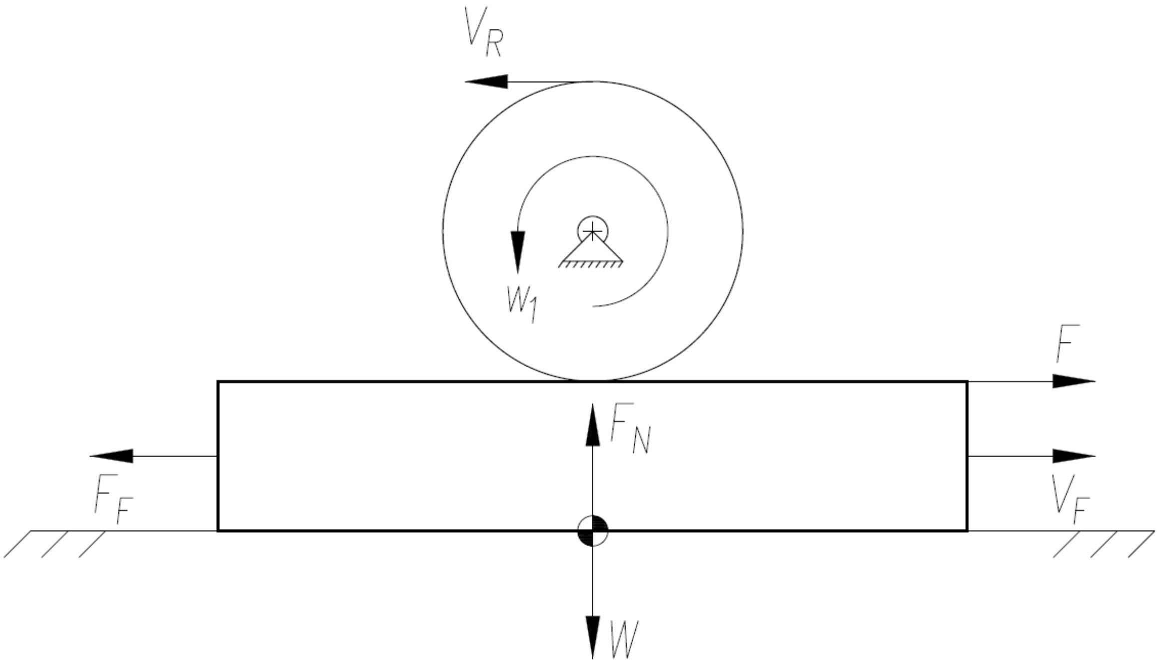

Figure 49 – Scheme of forces and velocities in case of sliding

The object is sliding on a surface with velocity V_F due to the force F which is applied by rotating wheel with angular velocity W_1. Friction of the surfaces prevents the movement and in order to move object the applied force F should overcome friction force F_f. According to the Coulomb's law friction force F_f in case of sliding is proportional to the pressure force F_N acting on the body. The dependence is expressed through the coefficient of friction μ which characterized two bodies rubbing against each other. Pressure force F_N is equal to the force of gravity W, or the mass of the object in gravitational acceleration g. [21]

$$\boldsymbol{F = F_F = \mu \cdot F_N = 0.50 \cdot 20700 = 10350\ N}$$

$$F_N = W = m \cdot g = 2110\ kg \cdot 9.81 \frac{m}{sec^2} = 20700 \frac{kg \cdot m}{sec^2} = 20700\ N$$

$$m_{max} = 2110\ kg - maximal\ mass\ of\ processed\ profile\ HEM\ 260$$

$$\mu = 0.5 - coefficient\ in\ case\ of\ dry\ static\ friction\ pair\ "steel - steel"$$

The work A to move an object is characterized by the applied force F at it and by passed path S. If acceleration a of an object changes in time then the work to achieve required speed takes the form of kinetic energy. The power N of a machine or a mechanism is the ratio of the work A to the time t during which it was made. [21]

$$\boldsymbol{A = F \cdot s = m \cdot a \cdot \frac{V_1^2 - V_0^2}{2a} = \frac{m \cdot V_1^2 - m \cdot V_0^2}{2} = \frac{m \cdot V_F^2}{2}}$$

$$\boldsymbol{A = \frac{2110\, kg \cdot \left(0.2\, \frac{m}{sec}\right)^2}{2} = 42.2\, Joules}$$

$$\boldsymbol{N = \frac{A}{t} = \frac{F \cdot s}{t} = F \cdot V = F \cdot V_F}$$

$$\boldsymbol{N = 10350\, N \cdot 0.2\, \frac{m}{sec} = 2070\, Watt = 2.07\, kW}$$

$F = ma - general\ equation\ of\ the\ force\ according\ to\ Newton's\ second\ law$

$s = \frac{V_1^2 - V_0^2}{2a} - traveled\ distance\ at\ rectilinear\ uniformly\ accelerated\ motion$

$V_1 = V_F = 12\ \frac{m}{min} = 0.2\ \frac{m}{sec} - minimal\ required\ processing\ speed\ set\ by\ analysis$

$V_0 = 0\ \frac{m}{sec} - initial\ velocity\ of\ the\ object$

5.2.3. Processing Block Technology

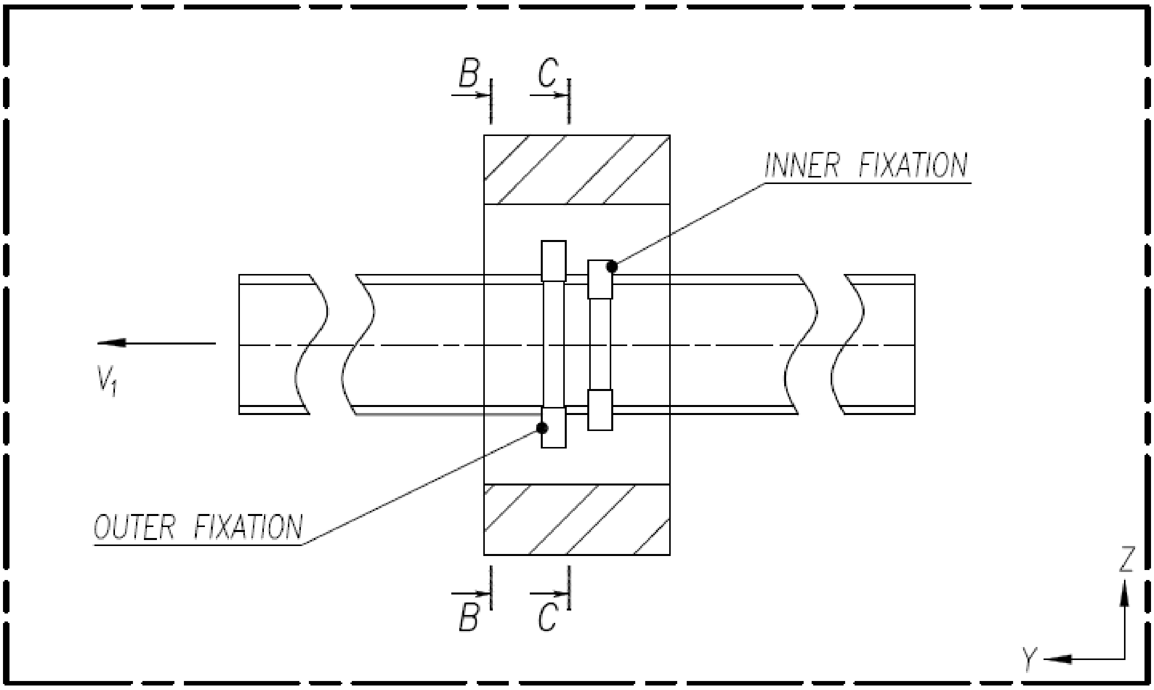

Figure 50 – Processing block technology scheme

The cutout of processing block is shown on Figure 50. Inner and outer processing is being done in separate modules equipped with 4 cutting blocks shown on Figure 51. Fixator sets required position of milling head which rounds sharp edges by rotating with angular velocity W_n. Holder main frame can change coordinates through guiding system. Cutouts "B – B" and "C – C" are shown on Figure 52 representing extreme fixation positions of different profiles. View "E" sets maximal dimensions of fixator.

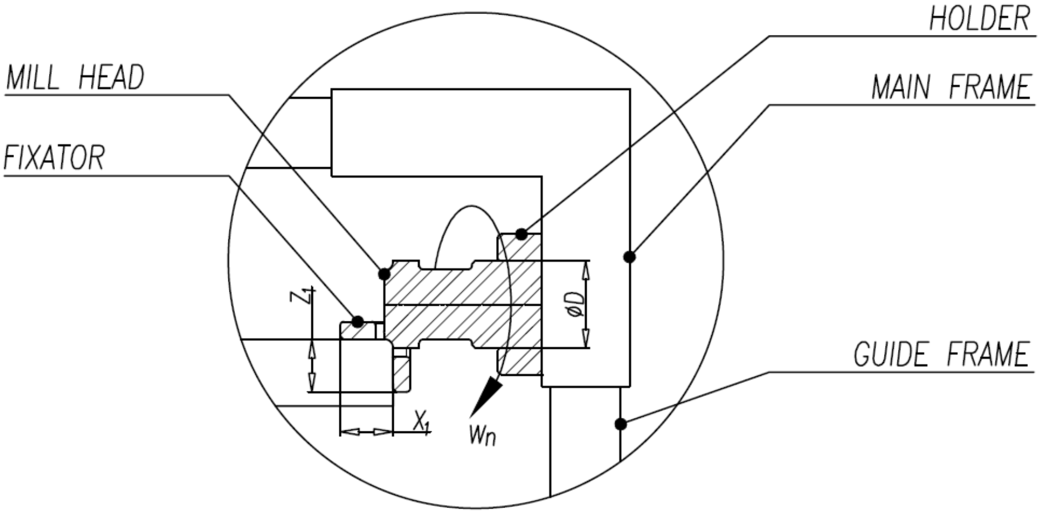

Figure 51 – Cutting block scheme

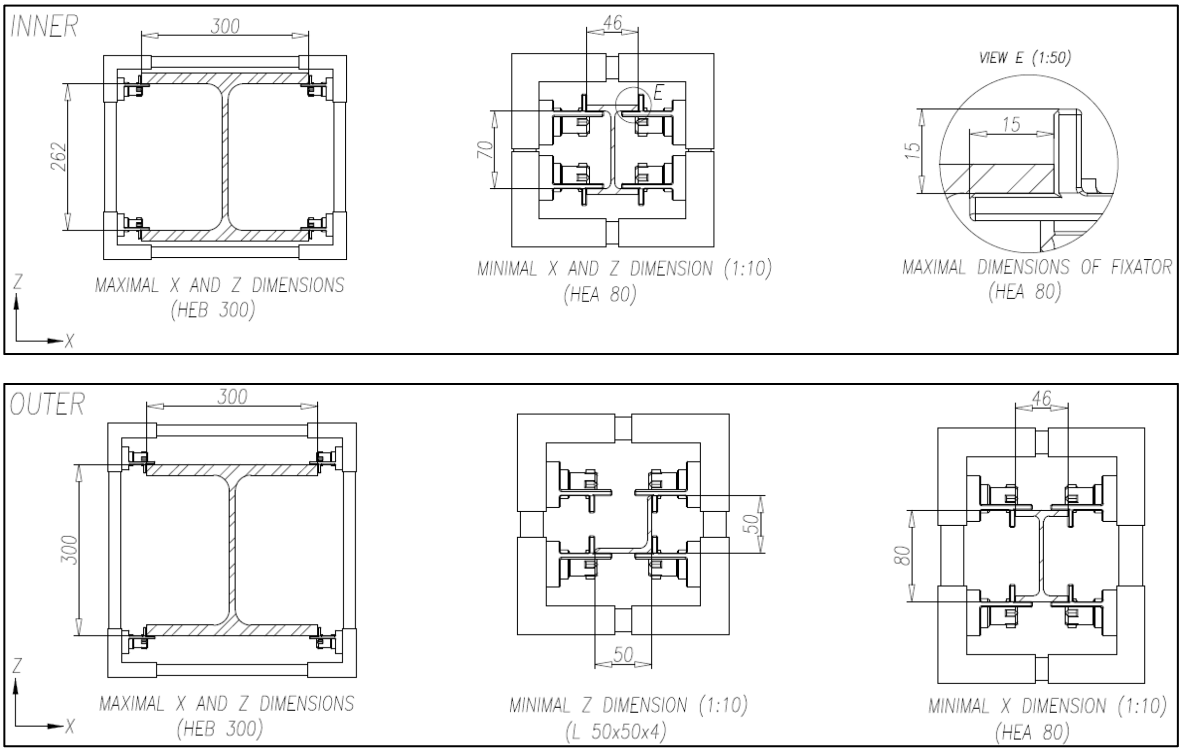

Figure 52 – Travel distances of cutting blocks and dimensions of fixator

Inner block distances:

- X_{min} = 46 mm
- X_{max} = 300 mm
- Z_{min} = 70 mm
- Z_{max} = 262 mm

Outer block distances:

- X_{min} = 46 mm
- X_{max} = 300 mm
- Z_{min} = 50 mm
- Z_{max} = 300 mm

5.2.4. Processing Block Parameters

Proper functioning of the systems is connected to cutting parameters which depend on many factors and set own boundaries. Before starting design of the milling center it is crucial to have all the necessary information in order to get actual results. According to research done we have next primary parameters:

- $V_f = V_1 = 12\,\frac{m}{min} = 12\,000\,\frac{mm}{min} - desired\ profile\ feed\ speed$
- $\emptyset D = 25\ mm - chosen\ milling\ head\ diameter$
- $z_n = 4 - chosen\ cutting\ inserts\ quantity$
- $Hardness = 175\ HB - material\ S355\ mechanical\ property$
- $R_m = 600\ MPa - material\ S355\ mechanical\ property$
- $w_n = n = 7500\ RPM - average\ angular\ cutting\ speed$
- $a_p = 0.7\ mm - cutting\ depth\ in\ case\ of\ 3\ mm\ radii$
- $a_e = 0.9\ mm - cutting\ width\ in\ case\ of\ 3\ mm\ radii$

Cutting speed V_c indicates the surface speed at diameter and forms a basic value for calculating cutting data. [22]

$$V_c = \frac{\pi \cdot D \cdot n}{1000} = \frac{\pi \cdot 25\ \cdot 7500}{1000} = 589\,\frac{m}{min}$$

Feed rate f_z is the relative velocity at which the cutter is advanced along the workpiece. [22]

$$V_f = f_z \cdot n \cdot z_n \rightarrow f_z = \frac{V_f}{n \cdot z_n} = \frac{12000}{7500 \cdot 4} = 0.4\,\frac{mm}{tooth}$$

Metal removal rate Q is the volume of metal removed in cubic mm per minute. It is established using the values for cutting depth a_p, width a_e and feed V_f. [22]

$$Q = \frac{a_p \cdot a_e \cdot V_f}{1000} = \frac{0.7 \cdot 0.9 \cdot 12000}{1000} = 7.56\,\frac{cm^3}{min}$$

Power requirement P needed for maching to handle the cutter and operation. It is established using the values for cutting depth a_p, width a_e, feed V_f, specific cutting force k_c (relates to the specific material resistance and in our case is 3240 $\frac{N}{mm^2}$) and efficiency η (min 70%). [22]

$$\boldsymbol{P = \frac{a_p \cdot a_e \cdot V_f \cdot k_c}{6 \cdot 10^7 \cdot \eta} = \frac{0.7 \cdot 0.9 \cdot 12000 \cdot 3240}{6 \cdot 10^7 \cdot 0.7} = 0.58\ kW}$$

Torque M needed to rotate milling head [22]

$$\boldsymbol{M = \frac{P \cdot 30 \cdot 10^3}{\pi \cdot n} = \frac{0.58 \cdot 30 \cdot 1000}{\pi \cdot 7500} = 0.74\ Nm}$$

5.3. Further Development

The chosen methodology until this point meant setting basic principles and parameters of work, giving an idea of what should be done and in what shape the machine should be designed. Specific qualitative and quantitative requirements have given an engineering background for further development of the project, namely according to the set boundaries the next stage would be detailing of the production line and it's modules. One of the options is creating a morphological matrix that represents some number of solutions for each node or element of the system. Proposed technology schemes made it clear that in order to make the process fully automotive different engineering disciplines should be involved in the project, therefore it is crucial to set next tasks:

- **Mechanical**
  1. Conceptual design detailing according to the set design requirements
  2. Proposal and evaluation of different concepts on the basis of efficiency, cost and feasibility.
  3. In-depth analysis and calculations of the chosen concept
  4. Release of the manufacturing documentation
- **Energy**
  1. Selection of power sources and energy delivery systems
  2. Creation of schemes and drawings for electrical works
- **Mechatronics**
  1. Expansion of the functional structure for the purpose of creating an algorithm
  2. Selection of tracking and tracing systems

The actual necessity and feasibility of rounding of sharp edges changes the meaning of this problem into the actual and serious task which is achievable only through collaboration of highly skilled and professional team members. Due to the fact that the initial topic had been set by the management of company Marketex Offshore Constructions, the further development and execution of previously specified tasks seems to be achievable. Therefore, results that had been obtained in the research to this pointed will be used as justification document which will be provided to the administration of the company for the purpose of getting resources required for further research and development. The information will be presented as design specification shown in Figure 53 and as the set of enclosed drawings.

Figure 53 – Design Specification Table

DESIGN SPECIFICATION	
TECHNOLOGICAL PRODUCTION LINE	
TYPE	**DESCRIPTION**
1. Function	**Rounding of sharp edges**

2. Conditions of Technological Process

2.1. Material

a. Form and Dimensions

	Min	Max
Angle Bars	50 mm	250 mm
H and I Beams	80 mm	300 mm
U Channels	50 mm	300 mm
Length	6 m	12 m

b. Type and Grade

Low alloy carbon steel
Max yield strength 360 MPa

c. Mass

Minimal	20 kg
Maximal	2110 kg

d. Processed sharp edges

Minimal	3 edges / cycle
Maximal	8 edges / cycle
Radii	Minimal 2 mm

Figure 53 – Extension of Design Specification Table

2.2. Movement and Positioning

a. Restrictions

Vertical Positioning Block		
Axis	Min	Max
X	25	150
Z	4	300

Horizontal Positioning Block		
Axis	Min	Max
X	4	300
Z	25	150

b. Parameters for 1 block

Minimal Feed Velocity	12 m/min
Maximal Force	10350 N
Maximal Power	2.07 kW

2.3. Fixation and Rounding

a. Process Method

Automated milling production line

b. Restrictions

Inner block fixation positions		
Axis	Min	Max
X	46	300
Z	70	262

Outer block fixation positions		
Axis	Min	Max
X	46	300
Z	50	300

c. Parameters for 1 cutting block

Minimal Service life	2 years
Minimal Power	0.58 kW
Minimal Torque	0.74 Nm

5.4. Economic Indicators

Justification of the project must always be supported by economic values that indicate the competitiveness and the actual need. The comparison shown below is made on the example of rounding of 8 sharp edges on HEB 300 beam using next machines:

1. Hand operated beveler (hereafter Hand)
2. HEXA smooth rolling line (hereafter HEXA)
3. Marketex Offshore Construction milling production line (hereafter MOC)

Figure 54 – Table of indicators in case of 6 meters of the profile

Description	Units	Hand	HEXA	MOC
Processing speed	Meters per minute	2	12	12
Edges at one pass	Quantity	1	4	8
Processing time	Minutes	24,00	1,00	0,50
Processing time	Hours	0,400	0,017	0,008
Pay rate	€ per hour	25	22	22
Costs	€	10	0,4	0,2

The first calculation shows that using milling production line time and costs are reduced by 50 times compared to hand operated beveller and by 2 times in comparison with abrasive technology.

Figure 55 – Table of indicators in case of 100 tons of the profile

Description	Units	Hand	HEXA	MOC
Processing speed	Meters per minute	2	12	12
Edges at one pass	Quantity	1	4	8
Processing time	Minutes	3416,00	142,33	71,17
Processing time	Hours	56,93	2,372	1,186
Processing time	Days	7,12	0,30	0,15
Pay rate	€ per hour	25	22	22
Costs	€ per hour	1423,3	52,2	26,1

In the second calculation were used 100 tons of HEB 300 which has length 854 meters and a total length of sharp edges is 6832 meters. The time needed for one worker to finish processing using hand beveller is 7 days, which is 50 times more than in case of milling production line. These numbers once more prove the necessity of the new system!

6. SUMMARY

The Master Thesis focused on the problem of rounding of sharp edges on specific profile types. This subject had been emphasised by the company Marketex Offshore Constructions which drew attention to the need of renewing and optimising operations connected to the processing method. Main reasons for that decision were high costs, ineffectiveness and harmfulness of the used equipment. Therefore, the initial goal of the research was to understand if there are existing solutions ready to be used on the site.

Through the study and exploration of the meaning and the reasons of the preparation of sharp edges on metal structures was uncovered extreme value of the rounding method. Further steps focused on finding existing solutions available on the current market and analysing their capabilities. Economic and technical aspects of the services offered by the enterprise showed that the present machinery and equipment offered on the market are unable to fully provide effective solution, thus revealing the actual need in the development of new equipment for the process of rounding of sharp edges.

Considering the most successful parts of the available machinery were established the concept idea of a production line with the milling processing method. This decision would guarantee the desired effectiveness and the quality of edges preparation. Moreover, machining processes are easily automated which reduces human efforts errors. For a more in-depth understanding of the designed system were done technological schemes and calculations of the basic parameters required for functionality of mechanisms.

Due to the fact that desired system represents complex engineering task demanding the use of multi-disciplinary team the last part of the research focused on creating design specification and drawings required for the further development. Since the implementation of the project depends on the decision of the company administration, additional justification of the competitiveness was done through comparison of different solutions. Taking into account that the data used in the calculations was minimal required for advancing among competitors, the value of the proposed rounding systems is real and the effectiveness can be improved by detailed engineering.

In conclusion it is important to notice that the proposed concept idea does not represent how exactly the production line has to be designed rather what has to be considered as basic principles and methods in further development of the production line. For the upcoming detailed engineering stage may be required additional study of technical and economic indicators to identify the actual position in the market niche. Despite the fact that the current processing system is represented in broad abstract form it makes clear the importance of design and engineering applied for rounding of sharp edges!

7. KOKKUVÕTTE

Magistritöö on keskendatud konkreetsete profiili tüüpide teravate nurkade ümardamise probleemil. See teema oli rõhutatud ettevõtega Marketex Offshore Constructions, mis pööras tähelepanu töötlemismeetoditega seotud operatsioonide uuendamise ja optimiseerimise vajadusele. Selle otsuse peamised põhjused olid suured kulud ning kasutatavate seadmete ebaeffektiivsus ja ohtlikkus. Seega, esialgseks uuringu eesmärgiks oli leida samalaadsete probleemide lahendamisel juba kasustatud ehk olemasolevad viisid.

Metalltoodete teravate nurkade viimistluse mõiste ja põhjuste uurimisel oli leiutatud suur väärtus ning tõeline huvi ümardamise meetodile. Edasised sammud olid keskendatud tänapäevasel turul saadaval olevate lahenduste leidmisel ja nende võimete analüüsimisel. Ettevõte poolt nõutud majanduslikkud ja tehnilised aspektid määravad et praeguse turu poolt pakutud masinad ja seadmed on võimatu tagada effektiivset lahendust, seega on avadatud tõsine vajadus teravate nurkade ümardamise protsesi uuete seadmete leiutamisest.

Saadaolevate masinate edukaimate osade arvesse võtmisel oli loodud uue tootmisliini konseptuaalne mõtte, mis on seotud freesimistöötlemise meetodiga. See variant tagaks soovitud effektiivsust ja servade ettevalmistamise kvaliteeti. Pealegi, mehaanilised töötlemisprotsessid on kergesti automatiseeritatavad, mis vähendab inimese jõupingutusi vigu. Põhjalikuma arusaamise jaoks olid tehtud mehhanismide toimimiseks nõutud põhiliste parameetrite tehnoloogilised skeemid ja arvutused.

Tulenevalt asjaolust, et soovitud süsteem kujutab ennast keerulist insenerilist ülesannet mis nõuab multidistsiplinaarse meeskonna kasutamist, viimane uuringu osa oli suunatud konstruktsiooni edasise arendamise jaoks nõutud spetsifikatsioonide ja jooniste loomisele.Kuna projekti saatus sõltub ettevõte administratsiooni otsusest, konkurentsivõime lisatõendamise jaoks oli tehtud erinevate lahenduste võrdlus.Võttes arvesse, et arvutustes kasutatud andmed olid konkurentide vahel edenemiseks miinimum-nõutud, pakutud ümardamissüsteemide väärtused on reaalsed ja nende effektiivsust on võimalik paraneda täpsema välja töötamisega.

Kokkuvõttes on oluline täpsustada, et pakutatava kontseptsiooni mõte ei selgita, kuidas täpselt tootmisliin peab olema projekteeritud pigem, mida tuleb lugeda põhi- meetoditeks ja -printsiipideks tootmisliini edasiarendamisel. Järgmise detailse projekteerimise etapi jaoks võib olla vajalik tehnilisi ja majanduslikke näitajate lisauuringute läbiviimine, et turu nišis tegeliku positsiooni kindlaks määrata.Vaatamata sellele, et praegune töötlemise süsteem on esindatud abstraktses kujus, on selgelt näidatud, kui oluline ja vajalik on disaini ja projekteerimist rakendada teravate servade ümardamisele!

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List of Appendixes

1. RS-FSD-01-00 - Revision 2: Function Structure Diagram
2. RS-SCH-GA-00 - Revision 2: General Technology Scheme Arrangement
3. RS-SCH-MP-00 - Revision 1: Movement and Positioning Technology Scheme
4. RS-SCH-PB-00 - Revision 0: Processing Block Technology Scheme (Sheet 1/2)
5. RS-SCH-PB-00 - Revision 0: Processing Block Technology Scheme (Sheet 2/2)