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## Elimination of constraints in the production process of power equipment components and the analysis of the resulting benefits

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### Abstract

The article presents the results regarding the elimination of constraints in the production process of a power equipment subassembly, a boiler chamber, together with an analysis of the benefits resulting from this, both financial and non-financial. The significance of bottlenecks in the production process, ways of its identification and limitations - in general - are presented. The article is a case-study of an attempt to eliminate the bottleneck in the production process of the boiler chamber, which turned out to be the process of drilling and marking-off, and work stations representing these processes. In order to eliminate the limitation, it was decided to replace the existing tracing and drilling work with a numerically controlled device - a boring machine moved from the liquidated department.. As a result, labor-intensive, manual chambers marking-off and the process of drilling holes with a smaller diameter drill have been eliminated. A number of benefits has been demonstrated resulting from the elimination of the bottleneck in the process, first of all, it was possible to reduce the duration of the marking-off and drilling operations and reduce the costs of the boiler chamber production process.

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## 1. Introduction

Every company is confronted with constraints that result in underutilisation of its production potential. However, not every company is aware of this and wants to control these constraints in order to support the flow of value (Ulewicz, 2013). In order to increase production potential, a limiting factor should be eliminated (Tomkowiak & Koliński, 2010). This factor is often referred to as the "bottleneck" (Pegels & Wauters, 2005).

A bottleneck in an enterprise is what prevents it from achieving its assumed better and higher goals, whether in terms of production, quality or profit (Mabin & Balderstone, 2000). Identification and breaking the bottleneck significantly improves the achievement of goals (Goldratt, 1990). Production bottlenecks determine the efficiency of the entire production system and may cause problems with the functioning of the company on a given market and with the production of high quality products (Hamrol, 2018). One of the basic aspects of production management is the identification and elimination of bottlenecks already at the planning stage, which will

enable starting production optimally using all resources (Hamrol, 2017).

It is widely accepted that the bottleneck in production is caused by a shortage of human and technological resources, and may also include activities affecting the production process such as data integration, document circulation or task management (Rahan, 1998). Interestingly, constraints can take many forms other than equipment (Nowakowska-Grunt & Mróz, 2013). A constraint or bottleneck can come in many forms, some applicable to manufacturing environments and some more applicable to services and knowledge work. The bottleneck is also seen as the work station with the lowest production capacity. This type of place limits the flow of goods and materials, while creating performance limits for the entire production system (Qassim, 2000). The bottleneck can be short-term, temporary - it can be a qualified employee on vacation or long-term, permanent - it can significantly slow down or even stop all production - e.g. a low-performance machine (Panizzolo & Garengo, 2013). The consequence of bottlenecks in production are possible production stoppages, oversupply, decrease in employee morale or loss of customers.

The bottlenecks can cause overloading of the machine, which can lead to damage or wear to the machine, which can result in potential downtime in the long run (Panizzolo, 2016).

Identifying bottlenecks is not easy. The main problem is that most of the bottlenecks are not static - they migrate. The bottleneck may change over time. For example, if a process fails, then the bottleneck can move to that process. To identify the bottleneck, a Lean tool such as: VSM, gembu walk can be used (Moor & Scheinkopr, 1998; Shrimali & Soni, 2018). The elimination of the bottleneck is an activity in the field of continuous improvement, which practically never ends (constraints will always exist), it is work on the systematic increase and development of production efficiency. (Trojanowska & Dostatni, 2017). Preventing a bottleneck would be ideal to avoid having to manage them and resolve them in the future (Hamrol, 2018). After a bottleneck is identified, three possible solutions can be employed to deal with it. The first one is to improve the efficiency of the bottleneck. If the bottleneck works faster / more efficiently, it will do more. The second is not to pass through the bottleneck things that someone else can do or can do otherwise. Finally, the third is connected with adding more power to the bottleneck (Zarzycka, 2010). The bottleneck is an object in the process that should be noticed and eliminated due to the great benefits for the company resulting from this fact. Eliminated or more efficiently used bottlenecks generate higher profits for the enterprise.

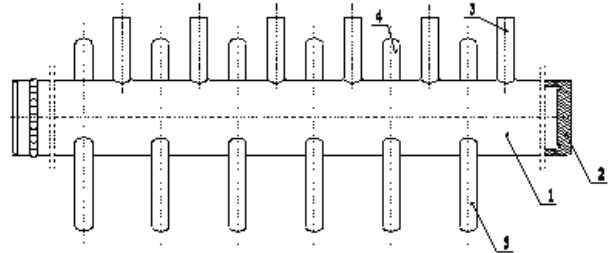
The purpose of the article is to present a case-study of an attempt to identify and eliminate the bottleneck in the production process of power equipment components - boiler chambers.

## 2. Experimental

The research object is the Boiler Elements Plant, one of the largest Polish companies involved in the design, production, construction and service of energy equipment and facilities. The plant produces boiler elements for the energy, heating, sugar and wood industries. In addition to the basic production of large power boilers, it also produces smaller boilers for the chemical and metallurgical industries as well as heat exchangers and pressure vessels. Large power boilers constituting 70% of the company's total production are used to generate electricity and heat energy used for heating housing estates and technological devices used in industry. The company is an enterprise with a unit production type and a very complex technology, which forces the specialization of workplaces.

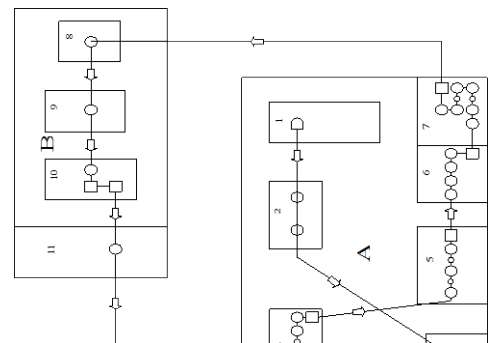
The tested products are boiler chambers. The task of the chambers is to connect elements of sheet piling and to collect and distribute the boiler's heating medium. The chamber is a part of the boiler in which the processes of accumulation and distribution of the medium flowing through the boiler take place, it is mainly water, steam or a steam-water mixture. Materials used for the production of boilers include various types of steel pipes, flat bars, sheets and rods. The chambers are made of steel pipes of different diameters, depending on the purpose of the chamber and operating parameters, bottoms blanking the ends of the pipe and ferrules of different diameters, sizes, shapes welded to previously drilled holes in pipes.

The view of the tested boiler chamber and its components is shown in Fig. 1.



**Fig. 1.** Boiler chamber and its components: 1. Boiler pipe, 2. Bottom, 3. Connection 1, 4. Connection 2, 5. Bent connection

Boiler chambers are produced in one of the two plants in the boiler chamber production department. The boiler chamber hall is equipped with seven work stations: 1) storage area, 2) marking-off station I, 3) turning station, 4) marking-off station II, 5) drilling station, 6) assembly station, 7) welding station. The chart showing the material flow for the boiler chamber through the production halls is shown in Fig. 2.



**Fig. 2.** Legend: A - boiler chamber hall, B - heat treatment and water testing hall. 1. Storage area, 2. Marking-off station I, 3. Turning station, 4. Marking-off station II, 5. Drilling station, 6. Assembly station, 7. Welding station, 8. Furnace, 9. Hydraulic press, 10. Water testing and acceptance station, 11. Paint shop.

**Fig. 2.** Chart of the material flow of the boiler chamber production process

The distances between individual work stations are not large and range from a few to several meters. Displacement of the processed material inside the hall is made using a crane. The gantry crane is served by two employees and they are usually people working at the positions to which the material is imported. Most machining stations are equipped with movable rotators enabling rotation of the work object and transport to another position.

The heat treatment and hydraulic testing hall is located 50 meters from the chamber hall. The welded chamber is transported to this hall by means of a battery trolley or railway wagons depending on the weight of the material being transported. The chamber is delivered to the furnace, where after annealing it moves successively to a hydraulic press, to a control station and to paint. For transport between these stations, a gantry

crane is used to equip the hall. After inspection and painting, the finished chambers are transported by transport vehicle to plant A or directly to the customer.

Due to the technological specificity of the chambers produced, the boiler chamber department did not meet the required expectations. Difficulties concerned the emergence of bottlenecks in production capacity at some stages of the production process, and the frequent failure to meet quality requirements. The chamber must meet very high requirements of material quality and accuracy of execution, because the medium flowing through it often has high temperature and pressure. Actions were taken to identify a bottleneck in the production process, to eliminate it and to improve the quality of manufactured products.

The observations of the production process of boiler chambers (gemba analysis) show that the most loaded workstation was the stand for marking-off openings for pipes in the chamber. Chamber marking-off consists in marking-off hole axes and placing holes along individual axes. Marking-off large chambers is a very labor-intensive activity, it requires precise positioning of measuring instruments and often 3 people are needed to perform these works. The production of various types of chambers required a lot of time and exceptional concentration and accuracy of the marking-off workers. However, employees sometimes made mistakes, which reflected in the product quality. The most common mistakes were not maintaining the accuracy of drawing dimensions when marking-off holes in the chamber. This led to reject of materials, to structural changes in the equipment cooperating with the chamber, necessary structural arrangements and often technical supervision opinions.

Other difficulties related to the production process of the boiler chamber concerned the process of drilling holes in the chamber. The drilling took place on a radial drilling machine operated manually by the drill. The chamber fastened and its axial rotation was also performed by an employee operating the station. Manual measuring devices were usually used to set the chamber in the right position, which did not always allow to maintain the accuracy.

The above-mentioned inconveniences were the reason to analyze work at these work stations and activities aimed at improving the production process of the boiler chamber.

### 3. Results and discussion

After analyzing the methods of work at all workstations (after gemba analysis) on the boiler chambers, it was found that the marking-off and drilling station are bottlenecks in the production process of the boiler chamber - they are characterized by high labor intensity and are burdened with frequent quality errors.

To eliminate this constrains, it was decided to replace the existing marking-off work with a numerically controlled device. Because the high purchase costs and the economic situation of the plant did not allow the purchase of such a machine, it was decided to use a device from the liquidated machining department - a numerically controlled boring machine. This

machine was moved to the chamber line department and, additionally, a turntable was adopted as a supporting device enabling the chamber to rotate around the axis by any angle. Because it is a boring machine characterized by precise and stable setting of the cutting tool, it has been found that it is possible to eliminate the laborious process of marking-off and drilling holes with a smaller diameter drill.

The versatility of the "new" machine went beyond the needs of the examined chamber production department, however, due to the benefits associated with the improvement of marking-off and drilling work in the chamber, the project was identified as profitable.

The boring machine was located in the place of the marking-off station next to the drilling machine. It was decided to leave the drilling machine in the department, now it has a supporting function in case of overloading at the drilling rig.

The actions of the employee operating the machine while drilling holes in the chamber compared to previous works have been significantly simplified. The machine is operated by one employee using a previously written program. The chart of team activities concerning drilling operations using the tested boring machine is presented in Table 1.

The comparative analysis of working methods at the boiler chamber department before the constraint is eliminated and after the constraint is eliminated, the following benefits are obtained:

1. The transport route between work stations in the boiler chamber hall has been shortened,
2. The manual chamber marking-off process has been eliminated,
3. The operation of drilling guide holes  $\varnothing 10$  mm has been eliminated,
4. The machine rotates the chamber on individual axes independently without human intervention,
5. Badly made chambers were eliminated,
6. The quality of chambers was improved.

Shortening the path of workpiece transport between work stations of the boiler chamber hall is shown in Fig. 3.

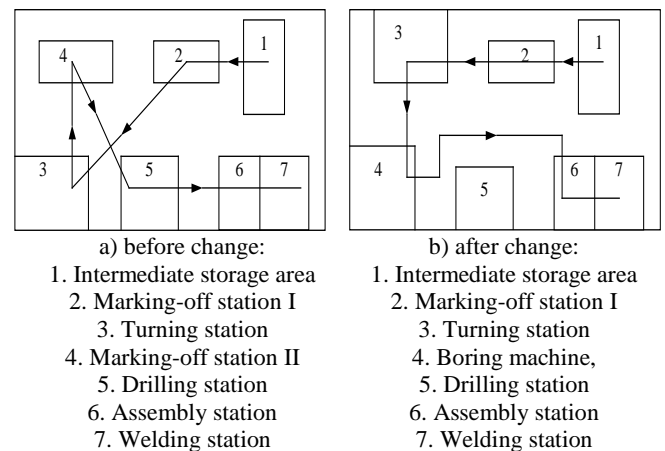


Fig. 3. A simplified diagram of the course of boiler chambers inside the hall.

**Table 1.** Team Activities Card for the process of drilling holes in the boiler chamber using a boring machine

NAME OF THE CARD		TEAM ACTIVITY CARD		MD			
THE OBJECT OF WORK: BOILER CHAMBER							
ACTION: DRILLING OF HOLES							
EXECUTOR: DRILLER							
START OF OBSERVATION: FIXING THE PIPE TO THE MACHINE							
END OF OBSERVATION: RELEASE OF THE PIPE							
A PLACE: DRILLING STATION							
PREPARED BY: M.M.			DATA:		CYCLE: 8 chambers		
CHECKED BY:			DATA:				
DRILLER			BORING MACHINE				
TRACK m	TIME min	SYMBOL	DESCRIPTION OF ACTIVITIES	TRACK m	TIME min	SYMBOL	DESCRIPTION OF ACTIVITIES
1	2	3	4	5	6	7	8
	13	①	fixing the pipe			①	pre-drilling
	4	②	putting on a drill ∅63.5				
	3	③	programming the machine				
	3	④	starting the machine				
	30	⑤	drilling		30	②	drilling
	1.5	⑥	turning off the machine				pre-drilling
	3	⑦	taking out the drill ∅63.5				
	3.5	⑧	putting on a drill ∅57				
	3	⑨	starting the machine			③	
	55	⑩	drilling		55		drilling
	1	⑪	turning off the machine				pre-drilling
	3		taking out the drill				
	7		unmounting the object				

An absolute reduction of downtime associated with waiting for the crane was obtained, however, the economic results turned out to be difficult to calculate due to the need for long-term observations of crane working times and stops.

A very important benefit, not only related to efficiency, but primarily with quality, is the elimination of chamber marking-off by employees. The marking-off of holes in the chamber has been done by hand by employees so far. These works were quite troublesome and required a long time. The axes were routed using measuring tools by converting the angles to the length of the pipe circumference. Due to the fact that some chambers had twelve or eighteen axes each, it was a lengthy process and also required many checking activities. An erroneous movement of the axis, and thus welding of the connectors was unacceptable, because the connectors had to be connected with other pipes previously made. Due to the fact that the chambers are installed at the boiler site, it was an unrepairable error. After improvement, these operations are carried out by a suitably programmed machine, which is equipped with preventing error systems of poor positioning for drilling. The machine itself sets the angle of each axis, as well as adjusts to the places of holes.

The employees who performed the marking-off were also fitters, therefore, the production capacity of assembling works

increased after the change was introduced. One of them together with an employee who has previously operated the drilling machine was trained to operate the new device. In this way, if necessary, it will be possible to accumulate work in two shifts in the event of a build-up of drilling work. Of course, in addition to the marking-off itself, marking-off activities have also been eliminated, such as placing on the rotary for marking-off, removal of the pipe, manual rotation for marking-off, etc.

Because the newly mounted machine is much more stable, stronger and adapted for drilling large holes, the operation of pre-drilling holes with a ∅ 10 mm drill is omitted. In an old drill, the drill had to be guided to drill large holes. The "new" machine does not require drilling, that is, the first operation is already the target drilling of holes.

The newly installed boring machine also has a turntable adapted to the fact that the once fastened object is rotated by the required angle without unfastening it and fastening again. The machine does it by itself and after setting in the correct position it gives a signal to the control device, thus activating drilling operations.

The analysis of the execution times before and after the change results in a significant saving of time in making one chamber (profit due to shortening of transport routes was omitted). Table 2 presents a summary of operation times.

**Table 2.** Duration of activities before and after the change

Before changing / eliminating constraints		After changing / eliminating constraints	
Operation	Time in [h]	Operation	Time in [h]
1. Marking-off	2.05	1. Marking-off	Does not occur
2. Drilling	3.45	2. Drilling	2.17
Sum	5.5	Sum	2.17

Table 2 shows that the time needed to make holes in the chamber decreases from 5.5 hours before the change to 2.17 hours after the change. This significantly influenced the efficiency of boiler chamber production. Assuming that the process of marking-off the chamber in question lasted 2.05 hours, 4 pieces could be made in one work shift. With an average of 176 hours per month, the average number of man-hours per year is  $176 * 12 = 2112$  hours, i.e. 2112 could be completed in one year:  $2.05 = 1050$  chambers. Since the chamber marking-off operations before the shift were performed by two employees, the annual labor intensity of the marking-off and drilling operations was  $2 * 2.05 + 3.45 * 1030 \text{ pcs} = 7776.5$  hours per year. The labor consumption for the drilling process using a boring machine is  $2.17 * 1030 \text{ units} = 2235.1$  hours per year.

An approximate calculation of the costs incurred by the plant for the marking-off and drilling process of the chamber before the change and after the change is presented in table 3.

**Table 3.** Selected costs of the boiler chamber production process

Calculation components	Before change	After change
Labour consumption	7776,5	2235,1
Salaries	50547	14528
direct wages	81381	23390
departmental costs	203452	58475
factory costs	284833	81866

The comparison of the difference in general plant costs, i.e. the price of the product before and after the change, results in savings = cost before the change - cost after the change, i.e. 284833 - 81866 = PLN 202967. PLN 202,967 is a significant saving, even if the cost of moving the machine, which was about PLN 12,000, is deducted. Nevertheless, it can be seen that the cost of annual profit significantly exceeded the expenditure incurred for moving machines. Practically, it can be said that within the first month the costs of expenditure incurred to eliminate the constraints were reimbursed.

Analyzing the above improvements in more detail, one should mention the important aspect of reducing quality shortcomings. Actually, the deficiencies have been eliminated. The device has two levels of protection against the possibility of errors. Frequent mistakes at the routing stage of the chamber production process were leading to the reject of the products. Because the chambers are made of high-grade steel, the cost of rejecting one pipe significantly increased production costs. The lack of a chamber was associated with bringing a new one. This, however, has never been easy, because manufacturers offered this type of material within 3-4 months from the date of order. The order had to be for a minimum metallurgical charge, i.e. bringing one or two pipes in a short time was simply impossible. The penalties that an establishment would have to incur for failing to meet the deadline for producing the product would often exceed the value of production.

One should not forget about reducing the costs of tools, i.e. Ø 10 drills, which are not needed in the production of chambers according to the new technology and the "new" machine.

In addition to the demonstrated economic savings, an important element is to improve the quality of the chambers produced. The plant is ISO 9001 certified, which is why great emphasis is placed on continuous improvement of quality. The elimination of the marking-off operation performed by the employee reduced the possibility of confusion, e.g. in the axis shift, in the incorrect arrangement of holes. In the whole improvement, a significant change is the limitation of the tracer's work and its replacement by a machine that has electronic security systems and after any wrong setting stops and does not make a mistake.

The installed device, due to its design and purpose, makes holes with very good smoothness and precision of workmanship. The distances between the holes are almost equal, with a very small difference not exceeding 0.01 mm, which is a very good result. The quality of products obtained also affects future plant orders for this type of product at home and abroad.

The measures taken to eliminate the restriction and improve the quality of the boiler chambers are an example of the implementation of quality assurance activities. In the production

of the tested product, the need for inspection at the department, i.e. at the place of manufacture of the product, was reduced. All possible errors are eliminated before starting the production process of the product. Emphasis has been put on the control of material ordering, design, ordering, etc. The company understood that a modern quality control system is based on the fact that less importance is attached to product control, and more importance to individual elements in the preparation of the production process. In addition to the economic effects, it was a benefit of the improvement.

#### 4. Summary and conclusion

The changes made in the examined company should be assessed due to the scale as relatively small, local, concerning a small number of people. These are adaptive changes that rely on the improvement of the system in the sphere of management, but do not lead to a change in its nature, approaching, in its sense, to undertake modifications. They result from the economic necessity to develop, improve the current functioning and increase its efficiency. They affect the daily functioning of the company.

The changes resulting from the elimination of constraints in the boiler chamber production process affected the related contractors: employees, management and administrative staff of the companies. They had to acquire new qualifications, switch to new working methods, change the nature and methods of supervision.

The employees who performed the marking-off were retrained as fitters, therefore the production capacity of assembling works increased. In this way, if necessary, i.e. accumulation of work at the drilling station, it will be possible to work in two shifts. The analysis of execution times, before and after the elimination of the constraints, resulted in a large saving of time in making one chamber.

The change related to the elimination of the constraints consisted in modernizing work stations by introducing a "new" numerically controlled device replacing manual work. The main purpose of this change was to increase work efficiency and the quality of manufactured products.

In the course of reflection on the essence of eliminating organizational restrictions and on the methodology and techniques for implementing them, it is important to emphasize the important role of management at all levels in initiating, controlling, co-implementing and assimilating them. Therefore, it can be said that the success of the process of eliminating constraints and obtaining positive effects depend to a large extent on the support given to them by the top management of the organization, and on the skillful "control of constraints".

The presented example of elimination of constraints in the production process of the tested product is not always possible to apply in the conditions of every other production plant. The article is a case-study on the elimination of constraints, where the criterion for choosing the direction of action was the cost of implementing the change. The project with the comparatively lowest costs was selected. The presented article indicates the need for a high level of management involvement in

the process of eliminating constraints and the need to constantly monitor the effects of such project and to implement corrective actions if necessary. One should be aware, that even the most carefully planned and implemented action in the area of elimination of bottlenecks may cause unexpected obstacles. It is, therefore, essential to constantly monitor and control the content and the process of eliminating constraints and to react to possible disruptions in a timely and consistent manner. The elimination of constraints is a process of continuous improvement, where after the elimination of one constraint there will always be or appear others. Therefore, it is important to be able to identify them and eliminate them efficiently. This can be done with the use of appropriate methods, tools and techniques, where the knowledge related to their use is supported by appropriate training of employees, or using the knowledge, experience and intuition of the employees themselves, who through observation and measurement only on site, i.e. in the hall, can indicate which process is a bottleneck, i.e. which should be first improved in order to increase its throughput.

The presented article proves that the process of eliminating restrictions can take place with a low expenditure of funds allocated for this purpose and using only the potential of internal resources.

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## 消除电力设备零件生产过程中的制约因素并分析最终结果

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### 關鍵詞

限制  
瓶颈  
能源产业  
消除  
好处  
成本

### 摘要

本文介绍了有关消除动力设备子组件，锅炉室生产过程中的限制的结果，并分析了由此产生的收益，包括财务和非财务方面的收益。总体上介绍了瓶颈在生产过程中的重要性，识别方法和局限性。本文旨在研究消除锅炉室生产过程中的瓶颈的案例研究，该过程原来是钻井和标刻的过程，而工作站代表了这些过程。为了消除这种局限性，决定用数字控制的设备（从清算部门搬来的镗床）代替现有的跟踪和钻探工作。消除了使用较小直径的钻头钻孔的过程。由于消除了过程中的瓶颈，因此已显示出许多好处，首先，可以减少标记和钻孔操作的持续时间，并降低锅炉室生产过程的成本

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