A study concerning the critical path method for optimizing the design and crafting of a welded structure

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Abstract. The paper includes a study on optimum batch calculation in designing the technology of execution of a welded structure within a company with mechanical profile, this being one of its main objects of activity. Because of the duration of different operations in the technological itinerary is not equal or in a multiple report, loading of machinery and workers cannot be done in a uniform manner, the production process being interrupted most often, narrow places and stocks large unfinished production, which is why we tried to determine an optimum manufacturing batch that would no longer allow these drawbacks. The solution of these problems is differentiated, considering the particularities of the manufactured product, the technological process, based on the economic analysis, aiming at the adoption of an optimal variant. The method provides the possibility to determine the influence of the size of the batch of parts on the duration of its production cycle.

1. Introduction
From the multitude of procedures or methods by which a product can be obtained, it is necessary to choose the one that produces the desired productivity, so that the chosen solution is an optimal one. [1]. The paper presents an application for the optimization of the design and realization of a welded construction structure of a company with mechanical profile.

2. Implementing the computing method of the optimum batch
From the analysis of the constructive solutions of the welded construction carcasses for different devices, they are made of components made largely in welded construction. They have a very large number of components of sheet metal of different sizes and are welded to constitute the parts necessary for the final carcass assembly. Typically, most carcasses are single or small series, which requires a welded construction solution as a favorite compared to casting, for example. [2]

One of the solutions offered by the company's marketing department was the organization of the production process of the "device housing" of the "steam generator" ensemble under the conditions of producing a production volume of \( N_g = 2400 \) pieces/year. The resulting data from the technologic crafting process for creating a piece are presented in Table 1.
The necessary working data for the organization of the production process are: The nominal time frame is $T_n = 1$ year, the working week has 5 working days, one shift per day, 8 hours per shift, the piece's weight is: $m = 65$ Kg, manufacturing is $R_f = (89+i\%)$, $R_f = 100\%$; The piece material is: alloy steel X6CrNi 18-10. The cost of the material is: - for steel $c_1 = 4.21$ lei / kg; the administrative preparation coefficient of the lot is $p = 25\%$; to immobilize the circulating means: $(1 + \frac{i}{100}) u.m / year$, $\xi = 0.21$ um / year.

To achieve appropriate quality joints, the subassembly will be controlled before the execution, during the execution and in the final phase, of [3]:

- The quality of the basic and added materials in terms of their correspondence with the project, the technical conditions of the project, the product standard and the quality characteristics,[4]
- The dimensions of the elements (pipes, nipples, caps) and their fitting into the deviations allowed by the project and the product standard;
- The condition of the surface of the elements and the compliance with the project provisions and the product standard;
- Compliance with welding technology for joints: round head welding, round corner welding (collector-sutures).

The regulations concerning the welding structure execution concern in particular [5]:

- approval of welding and control technology and procedures;
- authorization of welders;
- preparation (dimensions, aspects) of the joint for welding;
- compliance with the welding parameters (intensity - voltage);
- deposition of layers, temperature of the base materials during welding, electrode temperature, cleaning between layers;
- observance of heat treatment technology, temperatures, maintenance time, cooling conditions, furnishing of the furnace with appropriate measuring devices;
- control during welding, appearance, dimensions, non-destructive examinations;
- ensuring the absence of defects and the reduction of the thickness of the material in the areas in which the welds were made, of some parts after their removal.
- bookmarking, number and year of manufacture, brand, batch and/or batch of materials, product standard, welding indications;
- Hydraulic Pressure Testing;
- verification of product warranty documentation (technical book);

| The name of the operation          | Operative time $t_{op}$, min/ piece | Preparation end time $t_{pu}$, min/batch | The workforce wage lei/h |
|-----------------------------------|-------------------------------------|-----------------------------------------|-------------------------|
| Drafting plan for components      | 5+i/3                               | 50                                      | 4.31                    |
| Sheeting components              | 10+i/2                              | 38                                      | 3.10                    |
| Carrying out the coating of the welding | 2+i/5                              | 14                                      | 3.85                    |
| Drilling, threading              | 2+i/6                               | 14                                      | 3.62                    |
| Provisional clamping with welding heftures | 7+i/3                              | 18                                      | 3.93                    |
| Horizontal welding               | 8+i/4                               | 30                                      | 4.87                    |
| Vertical welding                 | 10+i/3                              | 35                                      | 5.02                    |
| Control                           | 4+i/5                               | 10                                      | 5.14                    |

Observations: $i =$ represents a marker number welded from the optimum batch

Table 1. The technologic process for creating a piece.
the existence and training of the specialized personnel for the non-destructive examinations and the usual control operations (material, appearance, size).

Details of the control operations, the documents on which they are carried out, the stages in which the process is carried out, the methods and means used and the documents to be issued are set out in the "Control Plan" [6]. The welded seam obtained by melting is obtained from the continuous melt formed from the base material at the edges of the welding components, to which most of the cases add an additional amount of addition or intake metal. It will consider the heat field distribution to welding to reduce the deformation of the welded components [7]. From the technological welding process itinerary were selected the main operations for welding the components of the carcass assembly in the Table 2.

| Nr. crt. | Name of the operation                          | Operative time t_{op}, min/piece | Preparation end time t_{pis}, min/batch | Workforce wage lei/h |
|---------|-----------------------------------------------|-----------------------------------|--------------------------------------|---------------------|
| 1       | De conserving and cleaning, (sanding, cleaning with disks and brushes, waste removal) | 9,66                              | 50                                   | 4,31                |
| 2       | Lining                                        | 10,66                             | 50                                   | 4,31                |
| 3       | Pattern sheeting                              | 5,2                               | 14                                   | 3,85                |
| 4       | Components sheeting                          | 16,5                              | 38                                   | 3,1                 |
| 5       | Processing the edges (polishing)              | 17,5                              | 38                                   | 3,1                 |
| 6       | Drilling                                      | 18,5                              | 38                                   | 3,1                 |
| 7       | Clamping with hefts in welding points         | 6,2                               | 14                                   | 3,85                |
| 8       | Longitudinal corner welding Changeable item-restraining ring | 19,5                              | 38                                   | 3,1                 |
| 9       | Nondestructive control                       | 7,2                               | 14                                   | 3,85                |
| 10      | Circular welding corner Pipe- plate           | 8,2                               | 14                                   | 3,85                |
| 11      | Nondestructive control                       | 9,2                               | 14                                   | 3,85                |
| 12      | Tip to tip welding Lid- pipe                 | 4,83                              | 14                                   | 3,62                |
| 13      | Nondestructive control                       | 5,83                              | 14                                   | 3,62                |
| 14      | Corner welding- Bolt- changeable item         | 11,66                             | 18                                   | 3,93                |
| 15      | Nondestructive control                       | 12,66                             | 18                                   | 3,93                |
| 16      | Polishing                                    | 11,75                             | 30                                   | 4,87                |
| 17      | Ensuring the lack of defects and reducing the thickness of the material in the areas where clamping welding of some pieces has been carried out, after their removal | 12,75                             | 30                                   | 4,87                |
| 18      | Painting                                     | 13,66                             | 35                                   | 5,02                |
| 19      | Highlighting the markers, numbers and years of production, brand, casting number and/ or material batch, product norm, welding indicatives | 13,66                             | 35                                   | 5,02                |
| 20      | Final control                                | 6,2                               | 10                                   | 5,14                |
The calculation data for the programming of the manufacturing process of the "device housing" assemblies are: The programming method used is CPM-Critical Path Method programming using network graphs (critical path method) in Figure 1. [8]

Figure 1. The problem’s main CPM tab.

There have been introduced the 20 activities, with the immediate predecessor activity and the top times, of the problem that we must investigate. The above activities are mostly one after the other, after each welding operation there is a non-destructive control activity to obtain quality welds. The duration of the 20 activities in the network graph is equal to the operative time top (rounded and expressed in hours) calculated for each corresponding operation (Figure 2), [9].

Figure 2. Information related to duration and cost.

2.1. Successive execution time
To all operation are given by the equation (1):

\[ D_{CO}^S = L_{ec} \cdot \sum_{i=1}^{20} t_{opi} \]  (1)
\[ \sum_{i=1}^{n} t_{opi} = 221.32 \]  \hspace{1cm} (2)

\[ L_{ec} = 50\text{min} \]  \hspace{1cm} (3)

It is one of the main parameters of the production activity management and serves as a basis for the production of the production programs of the sections and workshops, of the product graphs, of the production start date and execution, of the level and finishing of the execution, the unfinished production, the gaps between the stages of production, the need for circulating means and their rotation, as well as the characterization of the degree of organization of production in time. [3]

Successive execution times for all operations \((n)\) as follows:

\[ D_{CD}^5 = L_{ec} \cdot \sum_{i=1}^{20} t_{opi} = 50 \cdot 221.31 = 11065.5\text{ min} \]  \hspace{1cm} (4)

The advantage of the successive combination of technological operations lies in the fact that it ensures continuity of machines and workplaces throughout the period in which the batch of parts is being processed, and as a disadvantage - the long life of the operative cycle due to the expectation of the parts at each operation up to what the whole batch is processing for that operation. It also increases the volume of fixed assets in inventories of unfinished production.

The program also automatically builds the graph related to the problem, as shown in Figure 3. The critical road is rendered red on the direction of:

Start → A → B → C → D → H → O → P → Q → R → S → T → Finish

![Figure 3. The CPM graphic.](image-url)
2.2. Parallel organization of the optimum production batch
Under the conditions of continuous production, the parallel merging of the technological operations is specific, which consists in piece-piece transmission of the pieces to the next operation as they were completed in the previous operation.

In this way, a parallel, simultaneous development of the different processes of the technological process is achieved.

In practice, as a rule, technological operations have different durations, which leads to interruptions in the process of performing the operations, and thus during the operation of the machines.

The duration of the operative cycle under the conditions of the parallel connection of the four operations \(D_{co}^p\) is given by the sum:

\[
D_{co}^p = \sum_{i=1}^{n} topo_i + (L_{ec} - 1) \cdot topo_{max}\]

(5)

3. Result and discussion
We identify the operation “Longitudinal corner welding- Changeable item- restraining ring as being (topi) with the maximum value 19,5 and we replace it in the above formula:

\[
D_{cop} < D_{com} < D_{cos}
\]

(6)

It can easily be noticed that the duration of the manufacturing cycle in parallel is much smaller than in the series, which makes it preferable only if there are no interruptions due to technological operations with different production times.

Mixed organization is an improved version of successive but weaker organization than parallel organization, which makes it less useful as a method.

By comparing the first two operations, we find that, in the case of a parallel joint, the second operation systematically interrupts the operation of the machine and voids during the working time of the performer. These interruptions can be eliminated in the mixed joint by delaying the start of the second operation so that the first workpiece processed at the first operation will wait before proceeding to the next operation.

In relation to the duration, the operative cycle for the mixed joint is lower than in the conditions of successive and greater joining with the parallel joint.

4. Conclusion
Because of the duration of the different operations is not equal or in a multiple ratio, the loading of the machinery and the workers cannot be done uniformly, the production process being interrupted most often, narrow places and large unfinished production stocks, which is why we tried to determine an optimum manufacturing batch that would not allow these shortcomings.

Organizational measures are needed to avoid these negative phenomena, for example in poorly loaded jobs, work from other sectors may be distributed, production being carried out on lots, or if this is not possible, work can be done more cars served by one worker, for the full use of the available time.

The solution of these problems is differentiated, considering the particularities of the manufactured product, the technological process, based on the economic analysis, aiming at the adoption of an optimal variant.

The analysis of the calculation methodology of the operational cycle duration for the three forms of time-sharing of the technological operations offers the possibility to determine the influence of the size of the batch of parts on the duration of its production cycle.

For the other components of the production cycle, only those operations that do not overlap with production or standby operations, such as: section and workshop transportation of parts and subassemblies, are taken into account; finished product final testing, product test at the test bench,
durations of various natural products, those operations that require a great deal of work and involve discontinuation of the production process for their performance.

To achieve an optimum lot with a high productivity level, the following elements must be integrated into the production system: planning the process based on an appropriate program, establishing the manufacturing flow, implementing a control system of operations within the production process.

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