**Kaunas University of Technology**

Faculty of Mechanical Engineering and Design

# Case Analysis and Modernization of Progressive Die

Master’s Final Degree Project

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**Kaunas, 2021**

**Kaunas University of Technology**

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Industrial Engineering and Management (6211EX018)

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**Kaunas, 2021**

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# Case Analysis and Modernization of Progressive Die

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# Task of the Master's final degree project

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## 1. Title of the project

Case Analysis and Modernization of Progressive Die

*(In English)*

Žingsninio štampo analizė ir modernizavimas

*(In Lithuanian)*

## 2. Aim and tasks of the project

Aim: To examine progressive die structure and to apply modernization methods to improve efficiency of a specific progressive die.

Tasks:

1. To analyze general progressive die structure, design and its modernization methods that affect production efficiency.
2. To modernize a specific progressive die and to evaluate its efficiency.
3. To estimate progressive die cost and to calculate payback period if the existing progressive die was replaced with the newly developed one.

## 3. Initial data of the project

An existing CAD model of strip layout is used in this project for modernization.

## 4. Main requirements and conditions

At least 5 alternative blank nesting solutions has to be considered.

Maximum dimensions of progressive die has to be lower than 1 metre length and width. Shut height has to be under 0.6 m.

Modernized progressive die and its strip layout must be suitable for a maximum tonnage of 100 tons.

| | | | |
|---|---|---|---|
| Project author | Simonas Leonavičius | | 20 May 2021 |
| | *(Name, Surname)* | *(Signature)* | *(Date)* |
| Supervisor | Lina Kavaliauskienė | | |
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Study field and area (study field group): Production and Manufacturing Engineering (E10), Engineering Sciences (E).

Keywords: progressive die, strip layout, sheet metal, raw material utilization.

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## Summary

Sheet metal parts are in exceptionally high demand from various industries, such as automotive, aircraft, furniture or electronics. These parts are often produced by progressive dies, because they are precise and has high manufacturing speed. Since the costs of design, manufacturing and assembly of progressive dies themselves are relatively high, such tools are usually selected when the required volumes for sheet metal part is high. Naturally, because of this, even small errors in the progressive die design may lead to large quantities of wasted raw material, flawed sheet metal parts or other problems.

Based on global industry interest in moving towards sustainability, this research project attempts to analyse progressive die structure, its design phase and to review recent advancements in these fields. It was found out, that most of the recent improvements were related to software development and process simulations, such as blank layout optimization system development, trim line optimization, advanced springback predictions and more. Physical improvements were related to increased use in modular progressive dies and adaptation towards servo-driven presses. With gathered knowledge modernization methods were reviewed and blank layout optimization was applied to a strip layout of existing progressive die, since it has most impact on raw material utilization. 6 alternative layout solutions were considered, and the solution with best material utilization was selected while still being feasible. New strip layout and progressive die design was created using designated software for progressive die creation Logopress3. 2.15% increase in material utilization was achieved for researched strip layout.

Finally, progressive die cost estimations were carried out, using modern software FTI Forming Suite and its cost estimation tool based on sheet metal part feature length. Total progressive die cost was estimated to be 15915.49€ and payback period if the existing progressive die was replaced with the newly developed one, which was equal to 5.88 years.

Simonas Leonavičius. Žingsninio štampo analizė ir modernizavimas. Magistro baigiamasis projektas, vadovė doc. dr. Lina Kavaliausikienė Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Gamybos inžinerija (E10), Inžinerijos mokslai (E).

Reikšminiai žodžiai: žingsinis štampas, technologinė juosta, lakštinis metalas, žaliavų sąnaudos.

Kaunas, 2021. 57 p.

## Santrauka

Paklausa detalėms iš lakštinio metalo šiuo metu yra labai aukšta, jos yra naudojamos įvairiose pramonės sektoriuose, tokiuose kaip automobilių, lėktuvų, baldų gamybos ar elektronikos. Tokios detalės dažnai yra gaminamos žingsniniais štampais, nes šie pasižymi tikslumu ir aukštu gamybos greičiu. Kadangi tokio tipo štampų dizaino, gamybos ir surinkimo kainos yra sąlyginai didelės, toks gamybos būdas dažniausiai pasirenkamas kuomet reikia pagaminti itin didelius kiekius lakštinio metalo detalių. Dėl to, net ir maži žingsninio štampo dizaino trūkumai gali lemti neefektyvų žaliavų naudojimą, netiksliai pagamtintas lakštines detales ar kitas problemas.

Remiantis pasauliniu susidomėjimu tvaria gamyba, šiuo darbu yra bandoma tirti žingsninių štampų struktūrą, dizaino procesus, bei apžvelgti atnaujinimus šiose srityse ir atnaujinti jau esamą žingsninį štampą siekiant pagerinti jo žaliavų sąnaudą. Darbo metu sužinota, jog didžioji dalis naujų tyrimų buvo susiję su programinės įrangos skirtos žingsninių štampų kūrybai ir tobulinimui bei procesų susijusių su žingsniniu štampavimu simuliacijų vystimui, tokių kaip štampo technologinės juostos ar kirtimo linijos optimizavimas, metalo atšokimo per lenkimo liniją numatymas. Atlikus surinktos informacijos analizę, buvo pasirinkta atlikti technologinės juostos optimizavimą, kadangi tai turi didžiausią įtaką efektyviai žaliavų sąnaudai. Iš šešių technologinės juostos variantų buvo parinktas efektyviausias ir tinkamas žingsniniam štampavimui. Naujai sukurta technologinė juosta ir suprojektuotas žingsninis štampas naudojant modernią Logopress3 programinę įrangą padidino žaliavų sąnaudą 2.15 procentais.

Tyrimo pabaigoje, buvo numatyta žingsinio štampo kaina naudojant FTI Forming Suite programinę įrangą ir jos kainos numatymo pagal lakštinės detalės ypatybes funkciją. Nustatyta kaina — 15915,49€. Galiausiai apskaičiuotas laiko periodas per kurį atsipirktų naujas žingsninis štampas, jei jis pakeistų jau esamą su prastesne žaliavų sąnauda. Šis laiko periodas lygus 5,88 metams.

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# Introduction

Sheet metal parts of different shapes and properties are often produced by progressive dies. Such parts are required in a number of different industries: furniture, aircraft, automotive, electronics and so on. These industries propose immensely high demand for such parts. Therefore, sheet metal stamping industry is thriving even nowadays, there are lots of new improvements and developments, despite this industry not being relatively new [1, 2].

Because progressive dies on itself are quite expensive product to design, produce and assemble, it is selected as a manufacturing tool when the volume of sheet metal parts is high. As a result, even tiny errors and mistakes can lead to huge amounts of wasted raw material – sheet metal, faulty sheet metal parts of unacceptable quality or broken progressive die components. Nowadays, when there is more attention paid towards sustainability, efficiency of progressive dies becomes very important.

During the design stages of progressive die, part nesting in sheet metal coil is selected. It is very important to take careful and well considered choices, as part nesting and rotation heavily impacts sheet metal utilization and how much scrap metal is generated for each part produced. Applying optimization and modernization methods to progressive dies is of vital importance, because around three quarters of total manufacturing costs are consisting of raw material costs. Therefore, mistakes in progressive die design that affect material utilization can become very expensive during long term production [3]. As an example, when a progressive die stamps with 200 strokes per single minute for eight consecutive hours, one addition ton of raw sheet metal material could become utilized, if scrap metal waste is reduced by 10 grams for each part produced [4].

The aim of this research is to modernize an existing strip layout for a progressive die with modern software since it is most effective way to improve efficiency in material utilization.

Hypothesis:

After implementation of progressive die modernization methods, material utilization efficiency will improve by 2% and the project payback period will be 3 years or less.

Aim:

To examine progressive die structure and to apply modernization methods to improve efficiency of a specific progressive die.

Tasks:

1. To analyze general progressive die structure, design and its modernization methods that affect production efficiency.

2. To modernize a specific progressive die and to evaluate its efficiency.

3. To estimate progressive die cost and to calculate payback period if the existing progressive die was replaced with the newly developed one.

# 1. Research on progressive dies

Sheet metal material can be altered by metal stamping procedures in a number of different ways. Operations such as blanking, bending, embossing, drawing, piercing or forming are most common for this manufacturing method. Part material and structure of the scrap is affected by each and every operation of the progressive die.

When the volume of manufacturing is mass production, progressive dies are commonly chosen as manufacturing method. It has benefits of relatively low production cost and high precision with relatively very low deviation between different parts for the industry. Size of the manufactured parts ranges from small to medium-sized. Very small components such as integrated circuit lead frames for electonic industry or connectors for cellphone industry. Main working principle of a progressive die is that sheet metal strip moves from one station/position to the subsequent one, when the dies of progressive opens, and stops before dies closes and the operarations are performed onto the sheet-metal material.

Progressive dies has a complex structure that consists of hundreds of seperate parts that has different properties. As a result of this, it is beneficial to understand its structure and technological advancements of progressive dies, its design, structure and working principles. For this reason, first chapter analyses structure of progressive dies, strip layouts, software for its development, and recent technological improvements in this field. The general structure of progressive dies has a detailed analysis in “Manufacturing Engineering Handbook” by Hwiau Geng [5], with further details taken from “Handbook of Die Design” by Ivana Suchy [6].

## 1.1. Structure of progressive dies

As mentioned previously, progressive die stamping is one of the fastest and commonly used method for the sheet metal part manufacturing. Within the strip layouts of progressive die, segments of sheet metal parts and original coil are connected for the carrying of the part thoughout the different, subsequent stations within progressive die and is called the strip carrier. The design of strip layout and strip carriers varies for different sheet metal parts. Because of this gradual progression of the part, from one station to another where it is being cut, bended, formed and machined in other ways, this type of die is called “progressive”.

In the book “Design for Manufacturability Handbook” by James G. Bralla [7], it is stated that progressive dies are usually selected as the sheet metal part production tool, is because of the manufacturing speed, which varies from as much as 1500 parts manufactured per minute to as low as eight parts per minute. This volume is different because of many different factors, such as thickness of raw material for the part which is sheet metal, part size, press machine that is used for stamping, raw material properties, height of the stroke and more.

Progressive dies consists more than two of die sets that are different and separate and are allocated to different work stages (also called as work steps or work stations). Work stages are subsequent and timed in such manner, that the raw material which is sheet metal strip is fed through them for a constant and determined pitch (also called as progression).

Different work stations consists of die sets that has subsequent allocation as well. All of the die sets combined, forms a progressive die. In a single work stage, it is possible to perform operations on more than one part, and it is sometimes possible to apply multiple operations at once. A sheet metal strip passes through every work stage, in which it is trimmed, formed, sheared, bended, cut, etc. until a finished and complete part is seperated from the strip at the last work stage.

For progressive dies, the most common coil transferring system is coil feeding. When sensors systems are combined with coil feeding, progressive die can run without a human operator until the sheet metal coil runs out and has to be replaced. Sheet metal is most commonly provided rolls. In such cases, coil feeder and coil straightener equipment is required for a progressive die to operate. Coil feeder moves sheet metal throughout the progressive die's separate work stations by a determined progression (pitch). Coil straightener's purpose is to unwind the coil and to flatten it. There are several main advantages of progressive dies:

1. High volume of manufacturing with high speed of production.
2. Usually, no operator attendance is required when stamping press is running.
3. Only a single press machine necessary.

Main progressive die disadvantages are:

1. Usually, it is more expensive than other sheet metal stamping dies (line dies or transfer dies, that are less expensive, but require constant operator attendance and are slower).
2. Equipment with high precisions is required.
3. Additional relatively expensive equiment is required in order to be functional, such as coil straightener, coil feeder or other equipment.
4. If only a component of the progressive die, such as die set is broken, entire progressive die has to stop working and has to be disassembled in order to remove, repair and reinstall the broken part.

It is evidant, that progressive dies are composed of many separate sub-assemblies and parts, such as set blocks, die sets, springs, piloting pins among others. Following paragraphs defines progressive die parts in further detail.

### 1.1.1. Die sets and plates

Flat steel plates within progressive die are called die plates. Overall progressive die size is determined by the size of die plates and how many of them is installed within it. They act as a base, on which a number of different components are installed. Strict tolerance range is required for the ability to produce highly accurate sheet-metal parts.

Main sub-assembly of a progressive die is a die set. It consists of upper and lower shoes (lower shoe is sometimes called die shoe). Both lower and upper die shoes are made by milling and grinding with high precision and accuracy. It is important that these parts are made precisely, because it determines the quality and accuracy of the final, finished sheet metal part that is produced by progressive die. In some progressive dies, the upper die has a shank attached to it. Shank is used for tools' clamping and fixation to the ram of the hydraulic or other kind of press that is used for stamping. Fig. 1 displays two variants of generic die set with its components.

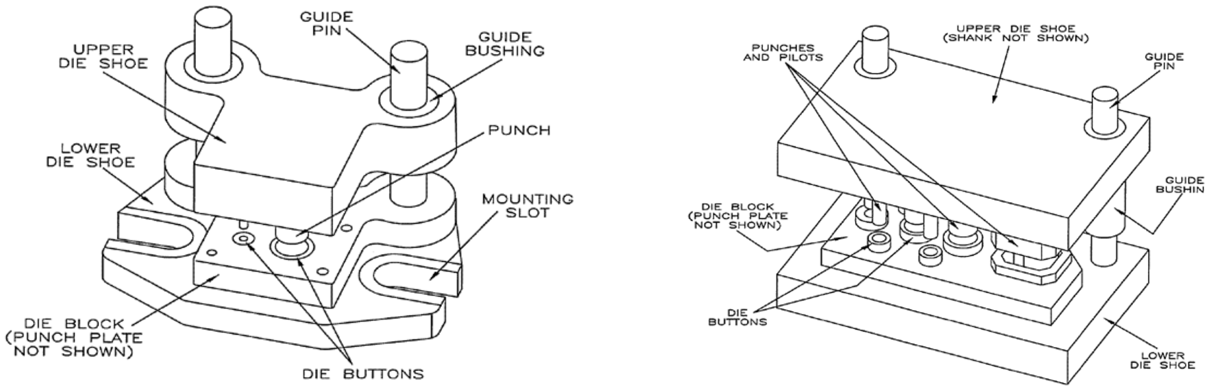


**Fig. 1.** Two variants of die sets and structural components [7]

In several cases, shanks are used not for clamping purposes, but to align the tool in progressive die.

There is a punch plate made from hardened steel mounted in the upper die shoe, in a similar way as die blocks. Its purpose is to hold components such as spring pads, punches, pilots, and others. Punch plates differs in size and shape, which is determined by the components that needs to be contained.

The strip of sheet-metal with workpieces moves over the surface of die blocks. To prevent misalignment risk, sheet metal strip is guided and secured by guiding rails or gauges.

### 1.1.2. Guide pins, bushings

Guide pins (sometimes called posts) aligns lower die shoes with upper die shoes. It prevents die halves from misalignment, thus eliminating the risk of precision loss. These components are fixated in the lower die shoes and are usually made from hardened tool steel. Respectively, bushings are installed in the upper die shoes to fit the guide pins when the progressive die is operating.

Guide pins and bushings are grouped in two types, ball bearing and friction type. Ball bearing type pins are an assembly of bearings, bushings, and ball cages. Guiding pins are contained withing ball cages and rides the bearings. Friction type bushings has a slightly bigger diameter than the guide pin. It has more friction than bearing type, therefore it generates more heat. Friction type bearings and bushings are less accurate than bushing type but are less expensive.

### 1.1.3. Keys, screws and dowels

The main group of components that secures separate progressive die parts to both lower and upper die shoes are screws. Screw head caps are hidden in the sockets that are milled in the die shoes.

Dowel pins are connecting 2 different components and fixes them in an alligned position, which is created when both ends of the dowel pin are secured into 2 separate components. Two or more dowel pins are needed for the alignment of a component pair.

As an alternative for dowel pins, keys can be used. They are blocks that has rectangular shape and are placed into accurately milled in the die plates and shoes.

### 1.1.4. Heel plates and heel blocks

Heel plates and heel blocks (sometimes reffered to as stop-blocks) are precise, steel components of progressive dies that has force absorbtion functionality. Sometimes they are welded to the lower and upper shoes, but more common fit technology is securing it with screws and dowel pins. Wear plates are integrated within heel plates and blocks, in order to absorb forces such as side thrust, that come from punching or bending stamping operations. Because of these components, thrust force has only single direction, thus misalgment or component failures are prevented.

### 1.1.5. Stripper pads

Stripper pads are a component of progressive dies that completely or partially covers sheet metal coil strip. It surrounds the area of a strip before it gets punched and has an opening for the cutting or forming punch. During the cutting or forming operations stripper pads secure the material and prevents metal deformations where it is unwanted, because material naturally collapses around the punch geometry. Usually, stripper pads are secured to the top side of the die block. These types of stripper are called stationary stripper pads. However, sometimes stripper pads are spring-loaded and secured to the punch plate. They are offset from the top side of the die block with the force of the springs.

### 1.1.6. Stripper pad springs

Springs act as a main force provider for spring-loaded stripper pads. A lot of different spring types are used in progressive die. These varieties are necessary to cover differences in separate progressive dies, such as pitch height, required force to secure the material before punching, total lifespan, cost and so on. Coil springs are a popular choice because they are relatively inexpensive but is some cases gas springs are used because they are less prone for failure and offers a wider force range.

### 1.1.7. Shoulder bolts

Shoulder bolts acts as a support for stripper pads and are preventing them from falling off. When progressive die starts closing, stripper pads gain enough support from lower die plates and shoes, therefore shoulder bolts no longer provide the support, until the die starts opening up once more.

### 1.1.8. Die buttons, retainers

Retainers (sometimes referred to as die buttons) are fitted to the lower die shoes. Die blocks has openings for retainers, inserts, die buttons and other components. These openings are precise, so the die bushings could be press-fit during the assembly works of the progressive die. To hide the heads of the bushings, relief pockets can be milled or drilled to the die blocks. During the repairs of the progressive die, retainers can be removed with ease, thus making repair tasks faster and less expensive.

## 1.2. Progressive die design

Usually, strip layout design is one of the most important steps in progressive die design. It determines how many stations progressive die will have, how parts will be nested and carried, how long is a single pitch progression, along with other important factors. When the strip layout design is finished, other components of progressive die are modelled according to the strip layout, because it determines shape and size of the punches. Following, shoe plates are modelled for punches, before other components can be added to the 3D model. In this chapter analysis strip layout design is provided.

### 1.2.1. Strip layout design

Strip layout depicts and establishes what kind of stamping procedures are required to produce sheet-metal part. Operation sequence, total number of stations, pitch distance and what will be performed at each station is also determined [6, 7].

Example of a strip layout and how part is nested within it can be seen in fig. 2. In the example, for a single part, total area is 159.94 millimeters high, and the width is equal to 38.1 millimeters. It can be seen that the pitch is equal to 40.46 millimeters. Distance between separate parts is 2.36 millimeters. Lastly, total width of the sheet metal coil is equal to 162.66 millimeters. Bend lines are also marked.

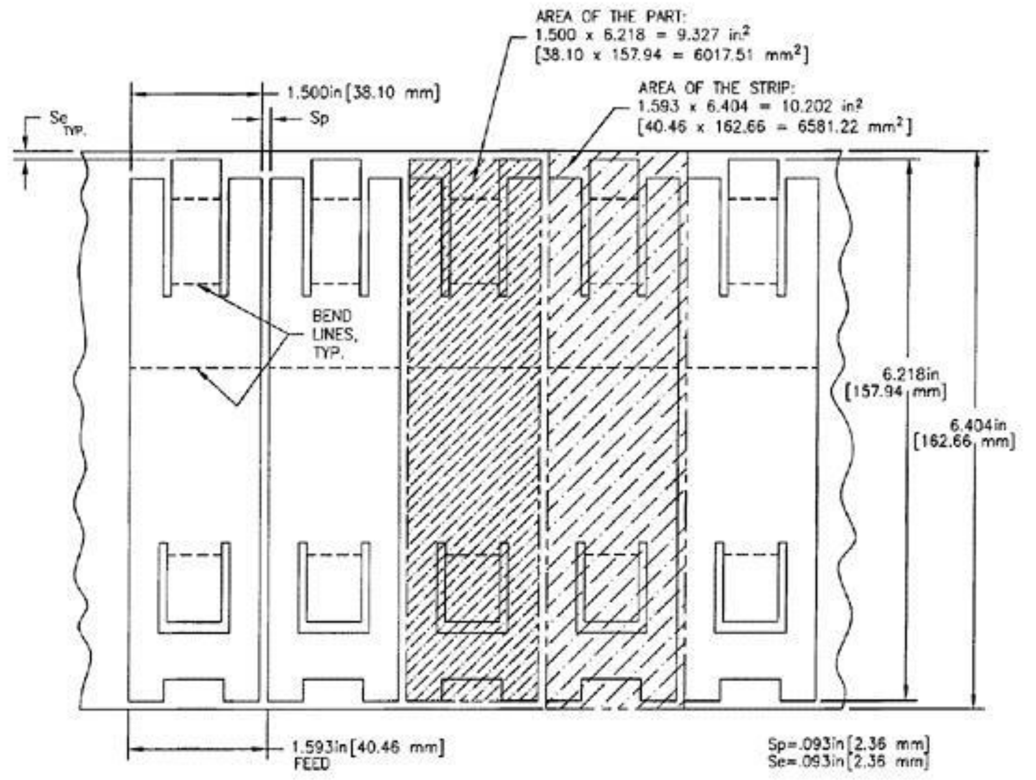


**Fig. 2.** Nesting of a sheet metal part [7]

Total volume of finished parts is the most important determinant on the design of strip layout. When the volume is low, strip layout design is generally kept simple, because there are less limitations on stamping speed and efficiency. Also, manufacturing costs for progressive die are lower in this case. However, when the manufacturing volume is high, additional importance is given to scrap rate and lifespan for progressive die, thus a more complex solution is commonly selected. The progressive die itself gets more expensive, but it has less impact on cost per part, because the volume of production is high [8].

After the preliminary volume evaluation, strip layout can be designed accordingly. The main factors that has most influence towards the design are volume (as mentioned earlier), manufacturer limitations, and preliminary value of tonnage. Manufacturers may put limitations because of press machinery that has limited availability. Progressive dies for flat parts require very low stroke height and parts that has a lot of high bends or three-dimensional profiles need press machinery with stroke height that fits for the geometry of the part.

A detailed strip layout can be developed, once the bed size, tonnage, stroke speed and stroke height are established. There are a lot of means of how parts can be nested: horizontally, vertically, intertwined with one another or at an angle. Normally, nesting is selected to have with lowest scrap rate while still being feasible and manufacturable. Fig. 3 displays a real-life example of a strip layout. It is visible that the part nesting is vertical. Pitch is almost equal to the width of the part, with added distance between separate parts. First stations are for piercing holes and contour cutting. Later bending and forming operations are applied, before part is cut off at the last station.

**Fig. 3.** Example of strip layout [9]

Good cost efficiency can be achieved when parts are nesting well, because progressive die can work fast with quick and short strokes.

An important step in strip layout design is to take consideration whether there will be enough space to place punches, holder plates, stripper pads and other such parts within the progressive die. Sometimes it is necessary to place idle steps where no operation is performed, so that there would be enough distance to fit separate punches or other die parts.

To design a sophisticated progressive die that has high complexity, an experienced design engineer is required. In such cases, it is important to plan operational sequence in optimal and correct manner. A lot of different factors must be considered beforehand, such as volume and tonnage, requirements and tolerances for part geometry, size and features of dies and punches, how the manufacturing process will affect the strip layout, and so on.

Strip layout usually acts as a skeleton or a main part within the assembly for a progressive die, because most components are modelled around it. When a noticeable feasibility issue appears, it must be eliminated as soon as possible before progressing with strip layout design, because it is very expensive to remanufacture a whole die.

A fully developed strip layout can be seen in fig. 4, that has been developed by Gui Li and his colleagues in their publication [10]. This strip layout is consisting of fifteen stations. In the beginning (stations from 1 to 3) holes and contour of the part are pierced. Stations from 4 to 13 are reserved for forming of the part. As can be seen, a number of stations are idle, because otherwise, there would not be enough space to place forming dies and punches.

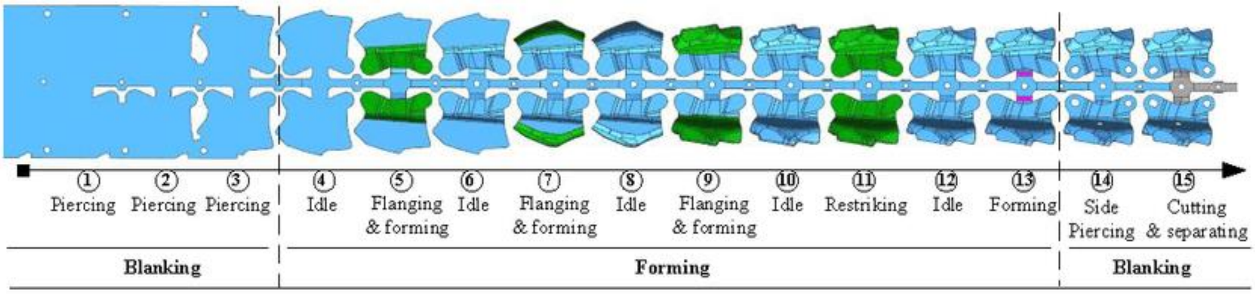
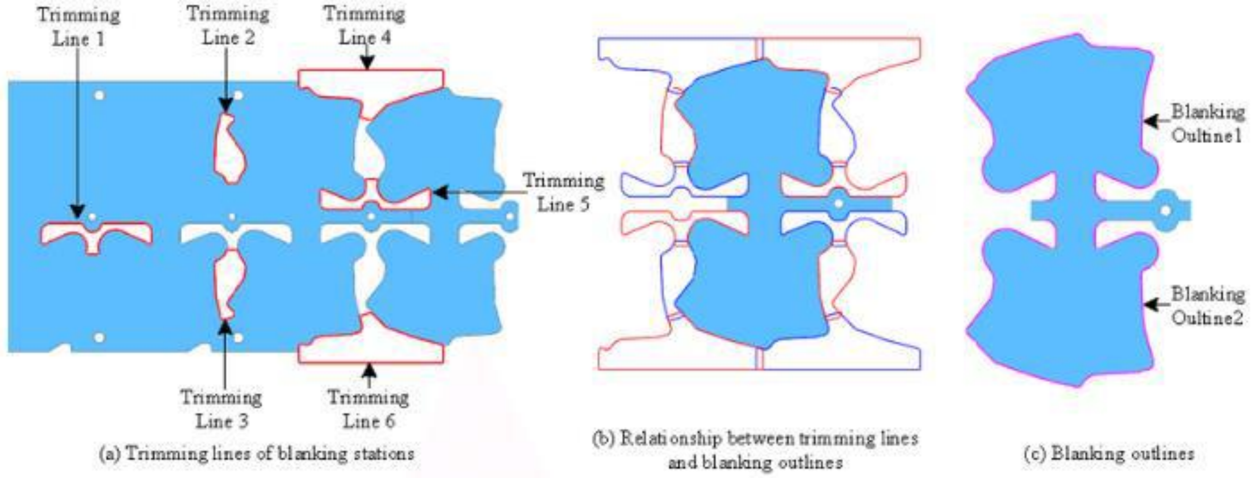


**Fig. 4.** Strip layout for automotive part [10]

Moreover, more detailed view of piercing operations is visible in fig. 5. Because the part has relatively complex outline, it is not possible to cut the outline in a single punch. For this reason, there are totally six punches that trims the sheet metal coil to match the outline of the 2 mirrored parts (not counting the last cut that separates the part from carrying strip).



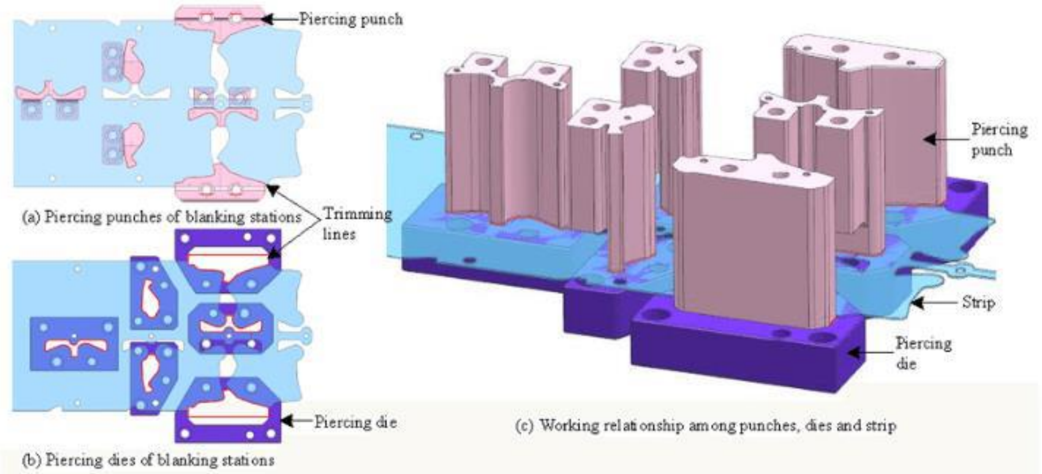
(a) Trimming lines of blanking stations

(b) Relationship between trimming lines and blanking outlines

(c) Blanking outlines

**Fig. 5.** Strip layout for automotive part [10]

Fig. 6 displays the same trimming punches, but with visible die plates. It provides information on how much space is needed for piercing die, and since it is taking significantly more space than punch itself, punches must be distributed to different stations to fit. Usually, in the design phase the shapes of the die plates are a subject to change, but it gives a general idea of how it will be distributed.



(a) Piercing punches of blanking stations

(b) Piercing dies of blanking stations

(c) Working relationship among punches, dies and strip

**Fig. 6.** Strip layout for automotive part, piercing dies [10]

## 1.3. Novelties in progressive die design and manufacturing processes

Most important structural elements of progressive dies and main principles of strip layout have been analyzed in previous chapters. It is required to understand progressive die structure and design intricacies to successfully analyze and understand novelties and improvements in die design and manufacturing processes that is performed in this chapter. Each of the following sub-chapters will describe most impactful, different, and recent improvements in this field.

Because the techonology of progressive die stamping has been used in various industries for decades, there are not a lot of physical, direct improvements. However computer aided design and simulations had a breathrough in the past years. It introduced a lot of advancements in progressive die design which will be described in the following paragraphs.

### 1.3.1. Modular parts for progressive dies

Progressive sheet metal stamping is perfect for high volume production. It is a preferred manufacturing method when the quantities of parts produced are high. However, when the number of produced parts is lower or there are a lot of configurational versions of one part, cost per part increases. Additional costs arise for lengthy setup procedures when die sets must be changed or replaced. To decrease these downtimes and make replacement procedures more efficient, modular tool systems are used, as described in an article from “The Stamping Journal” [11].

Progressive die stamping is fully automated process, which is not requiring attendance of human operator, except when the tool is stopped for coil restocking or for time consuming tool set changes. Efficiency is suffering because of this downtime, and as a result of that, some manufacturers started to make quickly changeable modular tools. One such manufacturer is “Steinel” that is situated in Germany [12].

Modular tool system is divided into three stages by the manufacturer. It is called three stage design. First is specific core structure of the machine. Second stage is the adapter plate that is specific to each tool and the last stage is consisting of changeable modules that are integrated to the adapter plate, as shown in Fig. 7.

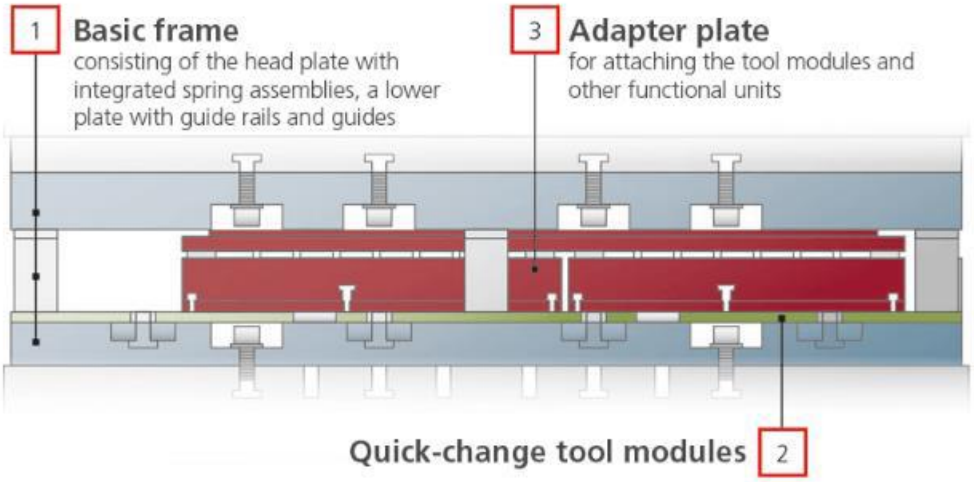


**Fig. 7.** Modular tool 3 design stages. 1 – Basic frame, 2 – Adapter plate, 3 – Quick change tool modules [12]

Lower and head plated long with guiding rails and guides are the core structural components for modular tooling system. Force for the stripper pad are generated from the springs that are integrated to the headplate. If the force requirements for the stripper pad are different, springs can be changed with suitable ones. This can be achieved with ease, because there are designated spring extraction points for that. Adapter plate that located on system's lower plate has preinstalled rails for sheet metal strip guiding along the die. Openings for scrap disposal are located on the lower plate. They are made as big as possible so it suitable to almost any tool. For easier tool change processes, bigger components like lifters can be placed on lower plate. According to the specific sheet metal part that is being manufactured, the main assembly can be modified by equipment that is required for such part's production [13].

Adapter plate is where different, separate function units (such as feeding control or cut station) are stationed. As a result, to replace complete progressive die tooling set, only adapter plate (or several adapter plates) with pre-equipped modules needs to be replaced. Therefore, tooling sets can be replaced very quickly and simply. Standard positioning and locking devices also help to prevent installation errors.

Tool modules are made of standard components along with pre-machined parts. Maximum module size is 35 centimeters. Heat treated and hardened components such as fixture plates for guides, springs and screws are installed to standard tool modules. From two to four ball bushings are contained in the modules, depending on its size. Visual and physical protections in the modules are prepared, to avoid wrong installation.

Modular system change times and design phase of progressive die are shortened when using modular tooling. Generally, this makes production more efficient. These systems reduce the downtime of the progressive die to less than twenty minutes, when custom progressive dies have several hour downtimes in comparison. Design phase becomes shorter, because there is no need to design a lot of smaller individual components. Because of this, "bottleneck" process can be eliminated when standard modular systems are in use, when short lead times are required.

### 1.3.2. Servo-driven presses for progressive die stamping

Recently, in progressive die stamping industry, servo-driven press use has been gaining popularity. A survey conducted by "Fabricators & Manufacturers Association Intl" states that within progressive sheet metal stamping industry, usage of servo-driven presses has increased nearly by three times, in year 2013. This relates to the increased demand for aluminum or steel materials with grades that have high strength to weight ration. Servo presses are attractive to manufacturers because it has a possibility to adjust speed and velocity of stamping, as well as, stroke height. Overall quality and effectiveness of overall operation can be changed as well. In traditional presses these parameters cannot be modified in the middle of stamping operation, not without changing the whole press.

Tim Heston [14], senior editor of the journal "The Fabricator" has published an article in which servo presses are described in detail and compares it to regular mechanical presses. While regular mechanical presses consist of main parts such as clutch, flywheel and motor, servo-driven presses have servomotor that can change and move slide axis in the middle of working. Traditional mechanical presses have the energy passed by the clutch from flywheel down the connecting rods, which are linked to the ram of the press. Required amount of momentum has to be gained by the flywheel, before punches hit sheet metal coil. Only with enough amount of momentum and speed of the stoke forming, piercing, and cutting operations can be performed successfully. For this reason, stroke height and speed are kept constant, when stamping is performed by traditional, mechanical presses. Meanwhile, servo presses can provide considerable amount of torque even when the stroke speed is slow.

Product manager in Ohio-based company Dayton, Shrinivas Patil [15] says that press and the progressive die can be damaged by stamping high-strength steel parts with mechanical presses by experiencing a lot of reverse tonnage loads, while generating a lot of scrap material.

There are a lot of advantages and benefits when progressive dies are designed to stamp with servo-driven presses. One of these are that the speed of the stamping can be changed in the middle of stroke. It is very beneficial when stamping such parts that require slow stroke speed (i.e. when performing a deep drawing operation). In such cases, it is possible to operate the press and progressive die in full speed and only to slow down when the complex forming operation is performed. Afterwards the press can return to full speed again. Such case would greatly increase production speed, because traditional press would have to consistently operate on the slowest required speed.

Another great benefit of servo press is that it can have its slide motion speed programmed. When slide motion speed is controlled, it is possible to reduce friction, thus transfer less heat to sheet metal coil and die components. This would lead to lesser usage of lubricants and possibly increase lifespan of the progressive die. In specific cases, having the ability to program motion speed could positively affect the way of how strip layout is designed. Sometimes, with programmable motion speed it is possible to perform same forming operations with less steps, thus decreasing the total length of progressive die.

Further advantages of servo driven presses are that it is more flexible than its counterparts, mechanical presses. Traditionally, progressive dies are design to fit specific mechanical press, because has less possibilities to be adjusted. Since servo driven presses have adjustable parameters, they are suitable for broader variety of progressive dies.

Lastly, when volumes of sheet metal parts that are stamped are very high, a lot of heat is generated. Over time this heat may cause the frame of progressive die to stretch slightly. This stretch would change the die height, and by some degree affect the sheet metal parts that are stamped. This problem is easily eliminated when using servo presses, by adjusting the slide height. If, additionally, sensor systems are adapted, slide height could be adjusted to match height of progressive die automatically.

### 1.3.3. Computer aided engineering related progressive die improvements

Progressive die industry could not be as prolific as it is without the use of computer aided engineering (CAE). CAE is used not only when strip layout and progressive die is designed, but also for performing additional, various process simulations. Such simulations as these enhances process planning and boosts efficiency. As stated in article “Die-Design and Sim. Software: What's New” by Lou Kren, recent and continuous improvements in quality, accuracy of computer performed simulation reduces the number of defects that reach manufacturing phase, and makes this phase more streamlined, reducing repair costs and error rate [16].

After the progressive die is finished, manufactured, it is tested with real work conditions. After the finished stamped sheet metal parts are measured, it becomes known whether progressive die produces accurate parts or not. If the tolerance restrictions for part geometry are exceeded, progressive die has to undergo additional changes and modifications until it produces part with correct geometry. These modifications are usually relatively expensive and are generally avoided beforehand.

#### 1.3.3.1. Die design based on simulations

As stated in study performed by M. Tisza “Recent development trends in sheet metal forming” progressive die lead time can be improved by integrating CAD software with simulation-based die modules. Such integration should decrease total cost of progressive die as well [17]. Majority of software which is used for 3D model creation of progressive die components or metal stamping process simulations has features that simulates die design based on finished sheet metal part geometry. This integrated feature rapidly creates forming punch or die surfaces by replicating part surface features. Some of industry leading software that has this functionality are “Logopress3” which is an extension to “SolidWorks”, “Catia” with “Process Designer” extension and “Autoform” [18].

#### 1.3.3.2. Trim line optimization and digital process planning

Like mentioned before, feasibility for strip layout is of vital importance for progressive die design. Upon it depends the shapes of trimming and blanking punches. Such operations cuts the sheet metal coil in order to match the outline of the produced part. Generally, the contour of the part is trimmed before forming operations are applied, because die trims from only one direction. When bending lines are straight and simple, it is not very hard to predict how the part outline would look before bending. Although, it is difficult to predict the flat outline for parts that will later be formed with complex forming punches. Before advanced computer software were used it was up to engineers to accurately predict the shape and outline of the part before it is fully formed. Within the sheet metal stamping industry, this prediction process is called part “unfolding”. When bending lines are straight, it is not difficult to calculate the outline of flat part by calculations based on material’s bend allowance. This value is determined by material properties, radius and angle of the bend and thickness of the sheet metal. With sheet metal forming industry becoming older, flat outline prediction for such bends are now very accurate and it usually reflects real life results. However, calculations based on bend allowance are not sophisticated enough to be suitable for very accurate outline prediction for parts that have curved bending lines. In such cases, there is a solution to manufacture a progressive with forming dies and punches but to take out trimming and cutting punches and dies. Instead of punching the outline of the part, several variants of outlines for the strip are separately cut by laser or water cutting technology. Such strip is then formed with progressive die, and the result is then compared with nominal values for the part. If the result values are not suitable, process is repeated. When the correct outline for the part is found, punching dies can be manufactured.

Article “Progressive die developed blank and trim line development” from magazine “Forming World” is describing how complex and difficult to predict sheet metal forming operations are solved by trim line optimization simulations that calculates and simulates forming procedures based on preliminary, suggested outline [19]. With this outline, advanced forming simulations is then performed. The results are then compared with target. If it is still not accurate enough the process can be repeated with multiple iterations, until results are achieved. Normally, multiple iterations are required until the required results are achieved, but it is also possible for digital process planning to display that the forming operation that is set up is impossible.

The use of trim line optimization and digital process planning has moved the metal stamping industry from trial and error methods using laser cut outlines towards digital simulations, and quite often reduces the number of real-life die try-outs. This shift also brings the benefits of reduced lead times for manufacturing of progressive dies.

#### 1.3.3.3. Accurate prediction of springback

In 2019, industry leading engineering software developers “AutoForm” published an article in “Metal Forming Magazine” where it states that expensive tool remakes can be completely avoided by predicting how metal will springback during the die design phase [20].

As mentioned in the article, springback occurrence is affected by a process called Bauschinger effect. It is where sheet metal flowing “on the tooling interface undergoes complex strain-path changes such as tension to compression, or vice versa” [20] during multiple loading or unloading cycles. Basically, it is a change in recently formed shape, which is caused by elastic deformation recovery. In progressive dies this happens every time when the progressive die opens and removes pressure from the newly formed parts. Bauschinger effect is visualized in Fig. 8.

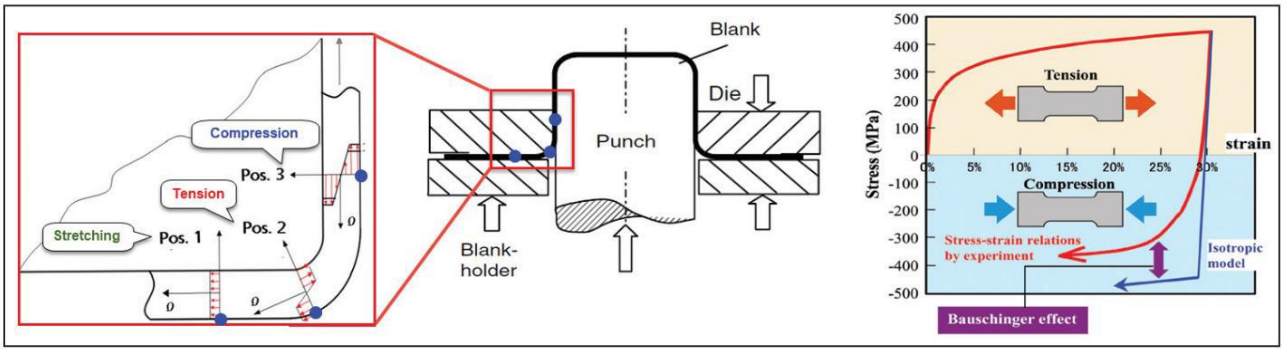


**Fig. 8.** Bauschinger effect [20]

Another article published by a company from United States, Michigan “Atlas Took Inc” is describing how it provides stamping services in low volumes, with mechanical or hydraulic press machinery. This firm uses already mentioned software “AutoForm”, which brings innovations to simulation-based metal stamping processes every year. Company engineers state that springback is accurately predicted when stamping 1.3 advanced high strength steel materials. Reportedly, costs significantly decreased when using springback prediction simulations than using traditional trial and error approach.

When it is necessary to reduce weight to meet application requirements, lightweight steel or aluminum sheet metal materials are selected which are relatively new in metal stamping industry (for example, advanced high strength steel. Since this kind of materials are prone to springback more than regular materials it is recommended to use numerical modelling calculations. To make bending punches more accurate, and to reduce error rate, advanced springback simulations can be performed. Springback for such materials as AHSS is caused by excess yield stress. Meanwhile, materials such as aluminum sheet metal springbacks due to low young modulus. Accuracy of simulation results for sheet metal forming or bending operations are determined by characteristics of material model and geometrical parameters such as elastic property range and plastic property deformations. Mentioned characteristics depends on hardening curve and yield surface. Moreover, when springback is required to be predicted accurately, strain/stress state, during and after the forming process, must be simulated precisely.

Normally, transformations of complex strain path and stress state reversal affects the material when forming operations are applied to it. This is caused by unfolding of the material after it is bent and due to repeated cyclic metal forming when it is formed over the die radius. Isotropic hardening model is often applied for material hardening and plastic deformation modelling. Attributes such as yield stress and Young's modulus are predicted with this model and it improves the process of springback prediction. [21]. Under the cyclic tension, sheet metal materials strain hardening differs, and is affected by Bauschinger effect as shown in Fig. 8.

In fig. 9, an AHSS rear cab automotive reinforcement is shown. It is visible how accurately springback is calculated with the use of kinematic hardening model. When springback simulations are applied in early progressive die design stages, significant costs of die and punch redesign can be completely avoided, which arises when finished part does not fit within its tolerance limits.

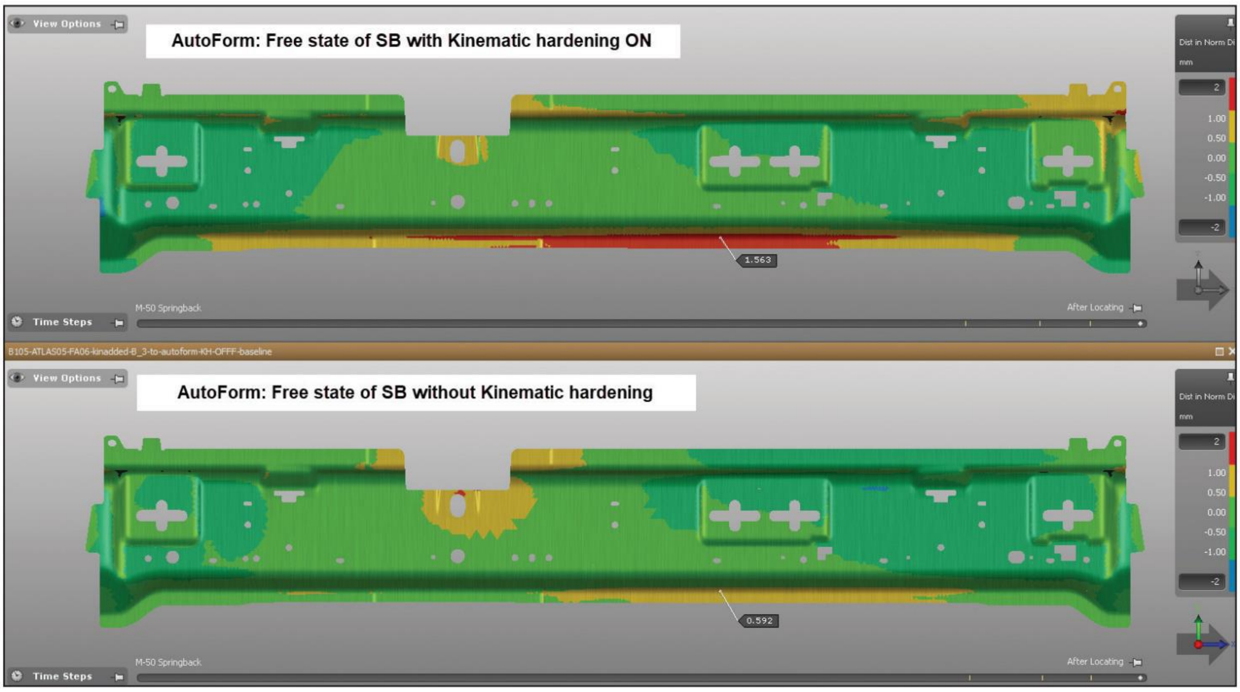


**Fig. 9.** Rear cab reinforcement springback simulation [20]

As stated in the article, when the simulation calculations take into account the Young's modulus degradation and kinematic hardening, springback prediction is vastly improved. "Autoform" a software designated for sheet metal forming evaluation and improvement, already includes kinematic hardening model in the simulations it performs, corresponding to the compression curves and cyclic tension for sheet metal undergoing formation processes. Therefore, this software is more accurate and reliable, when compared to its competitors. "Autoform" developers claim that in majority of cases, springback of very complex parts are predicted with no significant deviations from real life results even to complex parts [20].

Fig. 10 provides an example of a part that has experienced several forming operations, was later trimmed and lastly, measured for springback. If the simulation has correct initial data, such as correct material with its properties, CAD die models and control parameters, then the results will be reliable and accurate. In other words, the more inaccuracies there are in the initial data, the less accurate results will become. With inaccurate results it is more difficult to avoid costs of inaccurate part redesign and fewer financial resources are saved. In the Fig. 10, a scanned physical panel of measured part is visible. When comparing visual data in Fig. 9 and Fig. 10, it is clear that when kinematic hardening model is used, the simulation results are clearly more accurate.

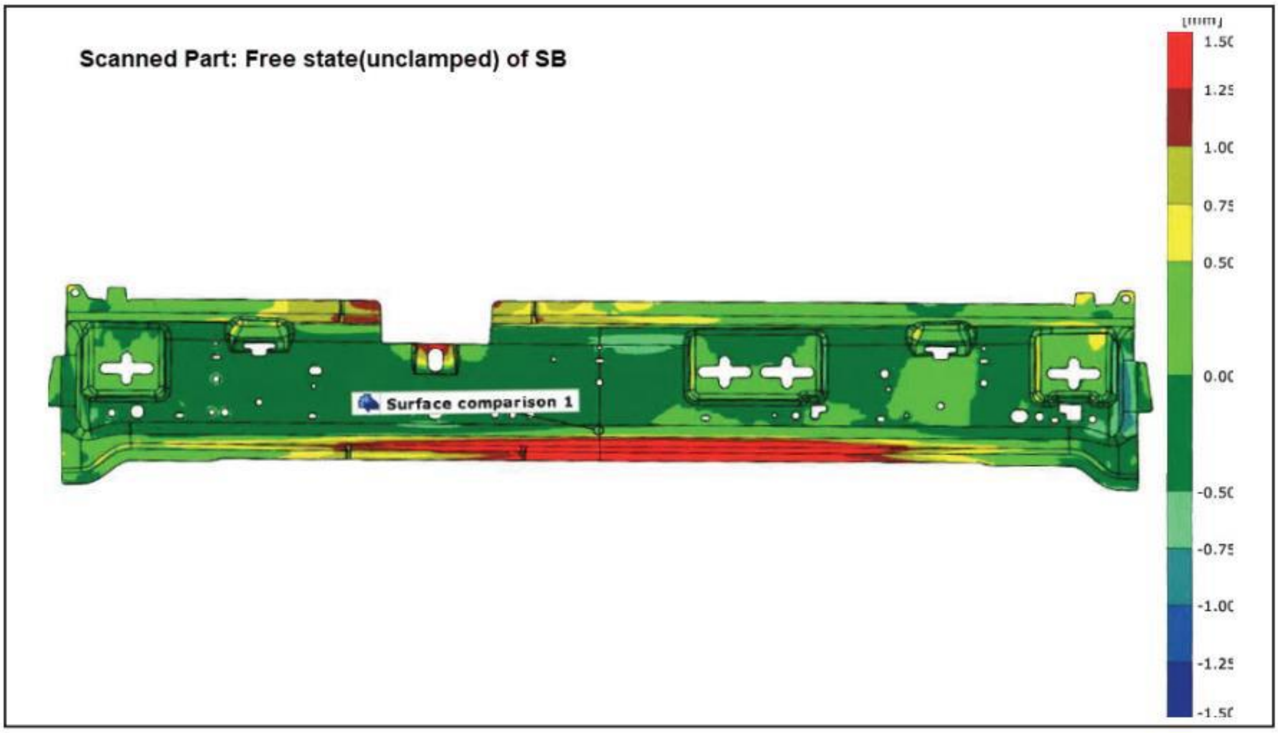


**Fig. 10.** Physical panel scan results [20]

Analyzed example signifies that the results with included kinematic hardening model are more accurate and reliable. The analyzed rear cab reinforcement was manufactured with transfer die, but this kind of simulation is suitable for parts stamped by progressive dies as well.

### 1.4. Progressive die modernization in existing works

As mentioned before, stamping of sheet metal is a manufacturing method that is relatively old and has been widely used for decades. Over the time numerous advancements have happened for this manufacturing process which is visible on the rising complexity of progressive dies that manufactures parts for different industry sectors, such as, automotive, furniture, electronics.

#### 1.4.1. Optimization system for blank layouting

Blank layout is a composition of multiple workpieces confined within sheet metal coil. Upon it depends strip layout design and the structure of progressive die in later design stages (for components such as die sets, stripper pads and other components). Strip layout is similar to blank layout but depicts main structural elements of progressive die, and what operations will be performed on a single part and in what order and station. Strip layout is probably the most important part of progressive die design. It can be described as composition of single blanks within sheet metal coil boundary, with visible trimming, forming, bending and other operations. Final blank layout is usually selected very carefully because material utilization and scrap rate depend on it. If optimal blank layout is selected, material utilization is higher and there is less scrap metal produced, when comparing to situation where a flawed blank layout is selected. Since majority of progressive die stamping costs are consisting of material costs, a lot of finances can be saved just by decreasing the scrap rate [22, 23].

Computer aided design and engineering changed the way how progressive dies are designed. Determination of blank layout was a manual task which was performed by design engineer and relied on his skills and experience. Because there are multiple and different factors to take into consideration when choosing blank layout, it becomes difficult to notice all flaws and make errors for a novice engineer.

To eliminate human error from this process, a lot of studies have been performed on this topic [22, 23, 24]. Engineers Y. Peng and Z. Zhao [22] have created an optimization system for finding the best blank layout solution and make this design step easier. Solutions as this are necessary for novice to experienced design engineers, to help throughout blank layout selection process and possibly reduce design development and overall production costs. Y. Peng and Z. Zhao have created a practical blank layouting system for optimization by using software AutoCAD and its toolkit ObjectARX. “Stamping Strip Layout for Optimal Raw Material Utilization” is another similar work performed by author T.J. Nye [4]. Both of these researched are described and analyzed in next paragraphs.

### 1.4.2. Principles of practical blank layout optimization

In progressive die industry, a blank can be defined as an outer contour of unprocessed and flatenned part contained within sheet metal coil or strip. This coil is later cut, trimmed and formed by a progressive die. Ratio between material that ends up as a finished part and remaining, unused sheet metal material is called material utilization and can be expressed with following formula, where η is material utilization, $n$ is a quantity of blanks that fits to a single pitch progression, $A$ is a value for complete area of the blank, $W$ stands for strip width [22]:

$$\eta = \frac{n \times A}{P \times W} \times 100\% \tag{1}$$

In most cases, only one or two parts are carried in a single pith progression, however, there are cases where 3 or more parts are carried. In Fig. 11 different layout modes can be seen, a single blank is depicted as an arrow.

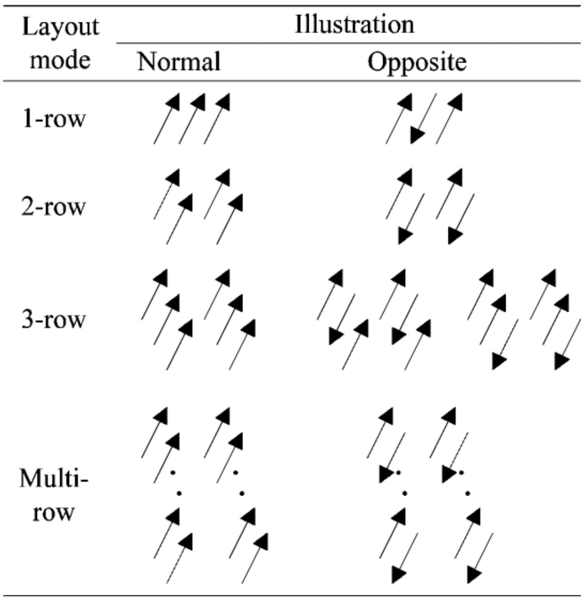


**Fig. 11.** Blank layout modes [22]

As already mentioned, one and two row modes are most common for progressive dies. Parts are nested in normal or opposite to each other for one row layout mode, and in opposite to each other for two row mode. Layouts that have separate parts nested at the same angle to one another are called normal, while opposite layouts have a straight angle of 180 degrees [6]. A more detailed visualization with most common modes is visible in Fig. 12.

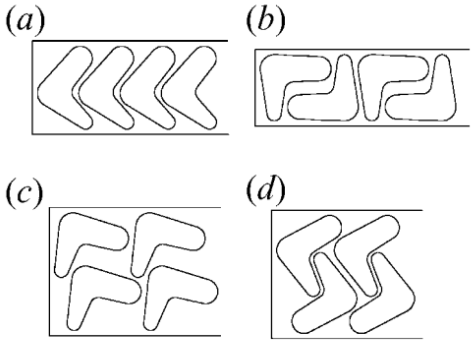


**Fig. 12.** Blank layout modes, (a): normal 1-row layout mode; (b): opposite 1-row layout mode; (c): normal 2-row kayout mode; (d): opposite 2-row layout mode [22]

The developers of practical layout optimization for blanks have defined six core principles, which represent the system [22]:

1. Highest possible material utilization ratio should be achieved. This principle is very important when production volume is high ir when the cost of raw material is high.
2. Grain flow direction should allign with bends of the part at a certain angle. When there is no or low angle between grain flow direction and bending lines of a part, it is possible for cracks to appear during forming operation for certain materials.
3. Limits for pitch progression and coil width. Limits for these variables are usually set by customer, depending on the available press machinery that is used for stamping.
4. Structural die design element consideration.
5. Pitch progression and coil width calculations in order to fit within the required limits.
6. Inclusion of carrying strip (sometimes reffered to as carrying web). Carrying strip can be defined as portion of sheet metal coil, a material that connects separate blanks. The carring strip is punched at the last station of progressive die, therefore finished parts are no longer connected strip layout and falls off to some kind of container. Minimum feasable distance between separate blanks has to be considered as well, because metal can not be punched with narrow punches. Such punches that does not meet minumum distance requirements may break during the punching operation.

### 1.4.3. Development of optimization system for blank layouting

Co-authors Y. Peng and Z. Zhao [22] have created a system for blank layout optimization which provides possible blank layout variants by acting on all six optimization principles that were described in previous paragraph. The structural plan of the optimization system is shown in Fig. 13. Plan selection is software element where user inputs the initial data, constraints and additional information by using system’s user interface. Pretreating processes initial data (constraints, direction of blank, width of the carrying strip and so on) while considering shape and outline of the blank. The user is provided with the results of the blank layout optimization that were calculated by the system’s algorithm. Ultimately, if the results are not yet satisfying the requirements set by the user, initial data can be altered to improve them. Full structural diagram is shown in Fig. 13.

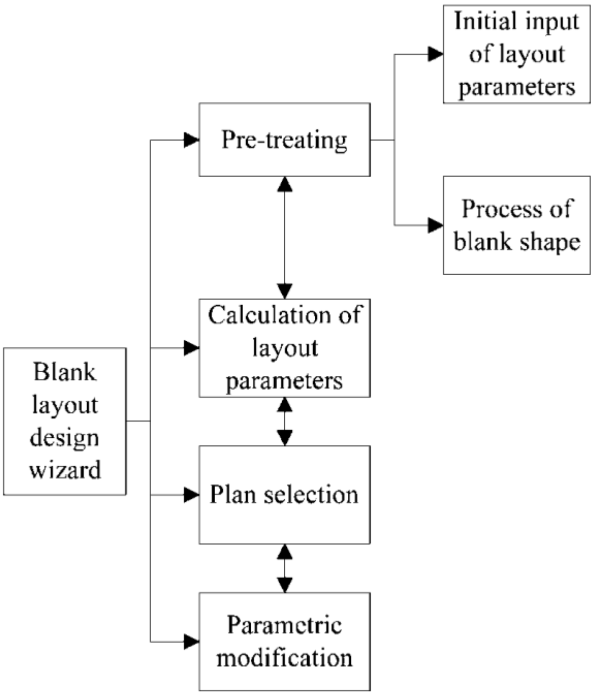


**Fig. 13.** Structural diagram for blank optimization system [22]

### 1.4.4. Trim line optimization

Progressive dies are very different from one another and has different characteristics and parameters. These characteristics include different number of stations, structure complexity, and strong correlation between those different stations. In order to improve raw material utilization or for some other reasons, a lot of improvement or optimization processes are applied both to new and already existing progressive dies. As proposed in chapter 1, most of the progressive die advancements and improvements are virtual, related to computer aided design and engineering, simulations, or complex calculations. In recent years, various software developers and engineering experts focused on developing optimal blank layouting software, as well as tools for trim line optimization [25]

#### 1.4.4.1. Accurate trim line optimization for strip layout

As mentioned before, progressive dies are distinguished by having multiple stations, precision, efficiency, and lengthy lifespan. It also can produce sheet metal parts of wide spectrum of complexity, from very simple to very complex. Such advantages are the main reason for focused development and innovation in progressive die stamping technologies. Previously, highly complex sheet metal parts were not produced with progressive dies, it was restricted to manual stamps instead. Such stamps require an operator to pick up part from one station and to place in the subsequent one manually. Fortunately, now this technology reached such level where manual stamps are chosen less frequently, because of development in computer performed simulations. Such simulations aid with the design of die structure, calculate and predict forming and cutting operations. But even then, this process is complex and time consuming when a progressive die is designed for a part that has complex shape and must undergo a lot of forming operations [25].

#### 1.4.4.2. Trim line prediction problem

Usually, strip layouts have from 4 to 20 stations for cutting, forming, trimming and other operations. The main problem is that normally, contour of the part must be cut before forming operations are applied. As a result, trim line has to be predicted before the progressive die is designed, because clients who order progressive dies for sheet metal part manufacturing usually provide only the drawings and requirements for a fully formed and finished part and rarely provide blank outline of the part. This leads to occasional errors and inaccuracies in design and manufacturing phases, and finished parts exceeds tolerance limits. If trim line prediction process is not accurate, the flaw can only be noticed during the real tryout of the progressive die after it is assembled. Such situations result in lengthy and usually expensive cutting and trimming die set redesign [26].

Furthermore, as mentioned previously, nowadays, progressive dies are often designed to stamp high strength steel sheet metal parts, specifically but not exclusively in automotive industry. Because of this, it becomes crucial to improve accuracy of forming operation simulations, as mistakes become very expensive. Luckily, solutions for this issue are solved by various software developers and engineers [26, 27, 28].

#### 1.4.4.3. Description of trim line prediction and optimization process

Researcher Gui Li in his report “Accurate trimming line of multi station progressive die for complex automotive structural parts” [26] focuses on unforming process of trim-line and bending, forming processes. Gui Li uses finite element methodology (often referred to as FEM) to simulate how sheet metal will act under forming and bending operations. Author developed new method for trimming line optimization based on iterative simulation of material’s strain path and claims that use of this method should reduce the number of required real-life tryouts of die sets. Inverse FEM algorithm calculates and predicts trim line for the part, based on the geometry of forming station. By regarding such factors as part model and its solid shell, forming die sets and stamping press, forming processes for complete strip layout are simulated. All strip layout stations are simulated at once, and with them being considered, optimization process can be split into six main steps.

1. Initial outline of the part is obtained. This is achieved by the method of inverse finite element. With this method, only initial blank of the part and finished part is taken into consideration. All of the intermediate station part geometries are ignored and disregarded in the calculations. Fig. 14 shows a mapped model of inverse finite element method.

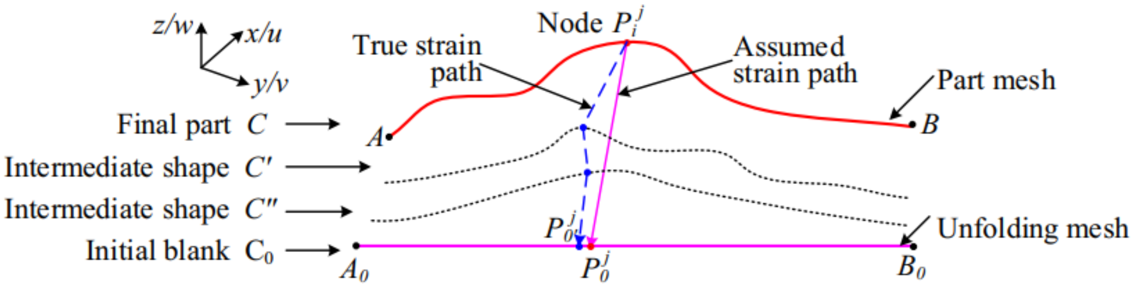


**Fig. 14.** Method of inverse finite element [26]

Afterwards, initial sheet outline is split into elements of preffered, adjustable size. Moreover, function of basis spline is used to create node spline which outlines the boundary.

2. Reffering to the part's outer shell, a numeric simulation runs for complete progressive die process. Node strain path direction is calculated from separate node relations and outline of the boundary, after the creation of forming operations.
3. Boundaries of both unformed and formed parts are then compared. Mapped nodes deviation is then measured and the results are then adjusted. Iterative optimization loop can be replayed until results are satisfying. Visualization of iterative loop optimization is provided in Fig. 15.

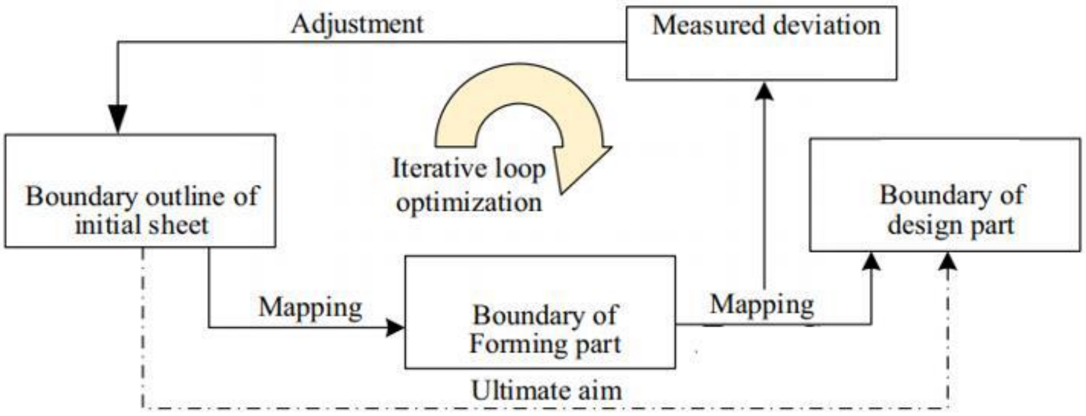


**Fig. 15.** Iterative loop trim line optimization [26]

4. Element strain in boundary nodes is then measured (with same directions as path strain).
5. Initial part boundary nodes are adjusted and placed onto the new curve of basis spline. This spline is used for the next cycle of outline optimization.
6. Previous steps from 1 to 5 can be replayed up until all of the nodes are not exceeding tolerance limits or until desired. Usually two or three iteration cycles are performed, but to reach more accurate results process can be replayed more times.

### 1.5. Conclusions on research of progressive dies

In this chapter progressive die structural components and design process is described. Further detail is paid to analysis of recent improvements in progressive die industry and how progressive dies can be modernized. For the conclusion of this chapter, following statements are formulated:

1. Progressive dies are consinsting of hundreds of separate parts and are generally complex. High accuracy and production speed are the main advantages for this manufacturing tool.
   Available industrial presses that are used for stamping has major impact on the design of the strip layout, because it has influence on tonnage, stroke height and dictates size dimensions for progressive die. Strip layout has big impact on it as well, because it determines such factors as pitch, part rotation within strip layout, total number of stations and other factors as well.
   When the structure of progressive die has high complexity, the choices in the strip layout design phase are very important.
2. In previous 10 years, progressive die manufacturing and design improvements were mainly digital: computer software and simulation development. Without CAE and CAD modern progressive die manufacturing development processes would not be possible because it radically improves design phases, streamlines manufacturing processes, removes a lot of trial-and error processes and cuts costs.

For low to medium compexity progressive dies modular tooling can be used which reduces down times for maintenance and increased their efficiency.

Rising demand for materials with high strength to weight ratio increases the use of servo driven presses for stamping sheet metal. This type of press has a lot of benefits when compared to traditional, mechanical presses, which often includes prolonged lifespan of progressive die and increased efficiency for manufacturing.

3. Optimization of blank layouting is vitally important in the processes of die design or modernization. When the parts are produced in high volume, even minor positive changes can net significant savings for manufacturing costs.

   It is important to note, that when performing progressive die modernization, sometimes it is better to select solutions that has not the best material utilization, because more factors has to be taken into consideration, such as feasibility, strip allignment to grain flow of sheet metal strip, additional manufacturer requirements, tolerance limits for the part, die structure element consideration and so on.

   Furthermore, a lot of manufacturing costs can be saved by using trim-line modernization methods. It is because deviation range is reduced, and the final part is more precise and is less likely to exceed specified tolerance limits, therefore less part remanufacturing processes are required. In current times, such simulations are known for fast and reliable performance and can decrease the number of expensive real-life tool tryouts for die forming operations.

## 2. Modernization of progressive die

In this chapter, initial data about progressive die is provided, as well as information about what improvements and modernization methods are applied. In later subchapters results with detailed conclusions are provided. Fig. 16 displays original strip layout of progressive die.

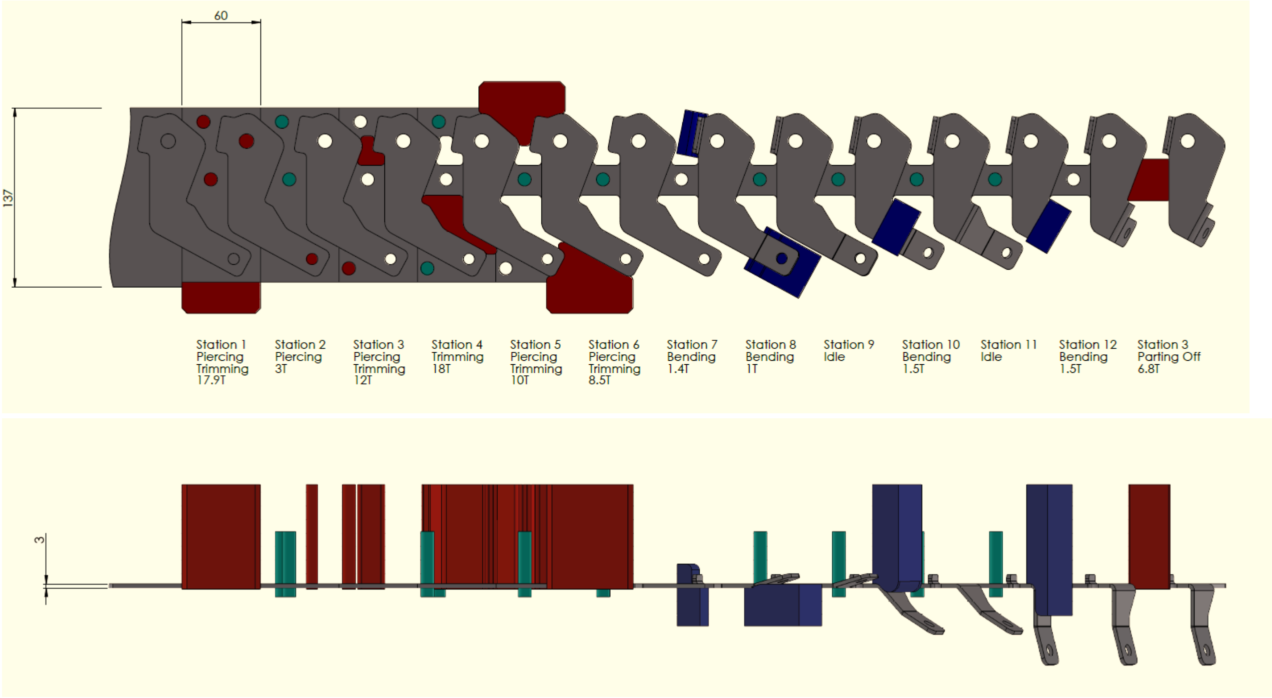


**Fig. 16.** Original, unimproved strip layout

Material utilization ŋ for this strip layout can be found with a previously mentioned formula (in chapter 1.4.2). $n$ stands for quantity of parts that are contained in a single pitch progression, which is equal to 1 in this case. *A* stands for total area of a single blank, this value is extracted from part's CAD model. *P* represents pitch progression value, which is visible in the Fig. 15 and is equal to 60 mm. Lastly, W stands for strip width. This value is taken from original strip layout, which is equal to 137 mm. With the formula, material utilization is calculated as 53.75%.

$$ŋ = \frac{n \times A}{P \times W} \times 100\% = \frac{1 \times 4418.58\, mm^2}{60\, mm \times 137\, mm} \times 100\% = 53.75\% \qquad (2)$$

### 2.1. Modernization of strip layout

Strip layout is acting as a central element of progressive die. Depending on it, all other main progressive elements are designed and modelled. Therefore, a lot of research focus is on this specific progressive die element.

### 2.1.1. Stamped sheet metal part

Fig. 17 displays a drawing of a stamped sheet metal part that is being produced by the progressive die which is analyzed and modernized in this research. Original drawing of the part cannot be provided, due to confidential restrictions issued by manufacturer. Therefore, a simplified version, only with the main dimensions is provided. The part serves as a bracket for a muffler assembly in a truck. The bracket is roughly 96 millimeters length, 47 millimeters width and 69 millimeters height.

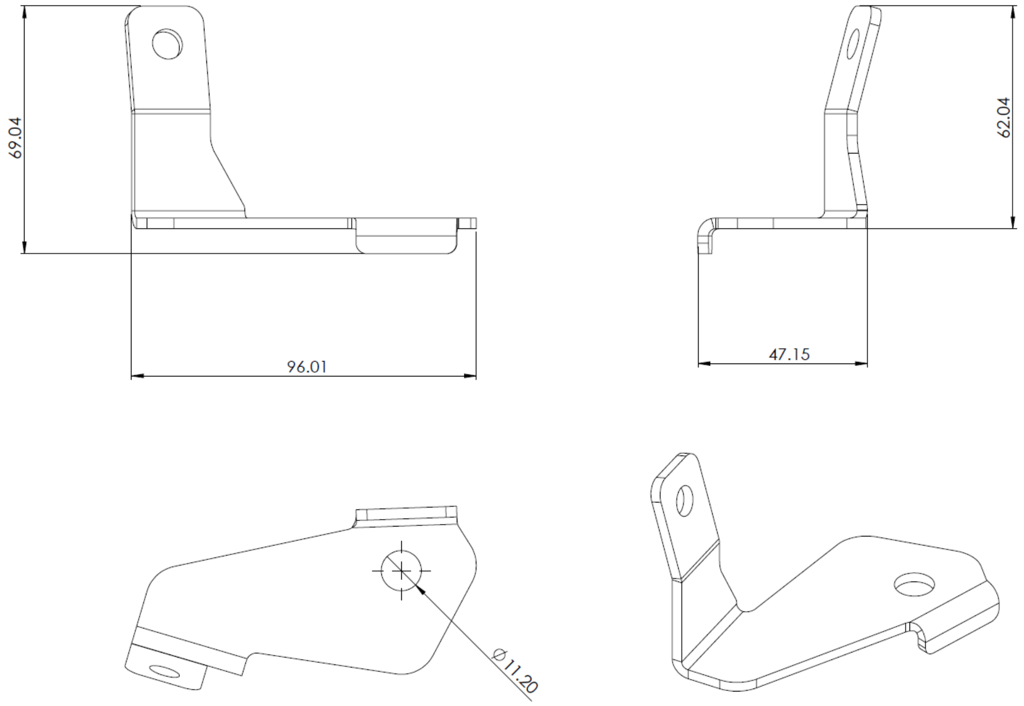


**Fig. 17.** Rear muffler bracket

Material of the part is graded as carbon steel S355MC. This material's parameters can be accessed by open database on materials "SteelGR" [29]. Main physical and mechanical properties for this material is provided in Table 1.

**Table 1.** Material properties for carbon steel S355MC [29]

| **Mechanical or physical property** | **Value** | **Unit** |
|---|---|---|
| Density | 7700 | kg/m$^3$ |
| Elongation | 8 - 25 | % |
| Fatigue | 275 | MPa |
| Tensile strength | 650 - 880 | MPa |
| Yield strength | 350 - 550 | MPa |
| Young's modulus | 200000 | MPa |

Chemical composition of S355MC is provided in Table 2 [29].

**Table 2.** Chemical composition of S355MC, % [29]

| **Carbon** | **Silicon** | **Manganese** | **Phosphorus** | **Sulfur** | **Vanadium** | **Niobium** | **Titanium** | **Aluminium** |
|---|---|---|---|---|---|---|---|---|
| Max 0.12 | Max 0.5 | Max 1.5 | Max 0.025 | Max 0.02 | Max 0.2 | Max 0.09 | Max 0.15 | Min 0.015 |

Furthermore, there are additional requirements for strip layout and progressive die that were requested by client. These are:

1. Additional trimming punch must trim 4 mm of sheet metal in the first station of progressive die, as in existing variant of strip layout. It is a design choice which prevents coil to overfeed.

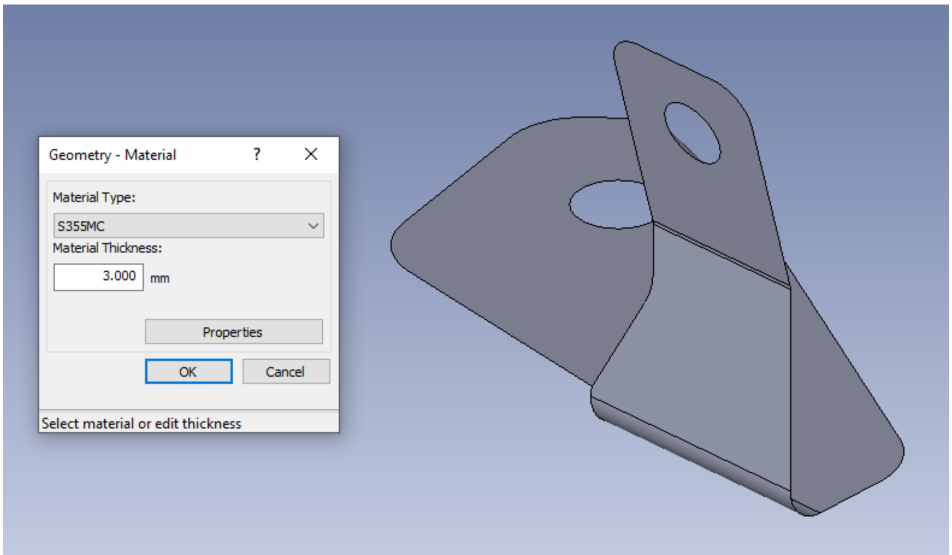
2. Progressive die tonnage must be lower than 100 tons.
3. Maximum dimensions of progressive die has to be lower than 1 metre length and width. Shut height has to be under 0.6 m.

### 2.1.2. Optimal blank layout selection

In order to select the best solution for blank layout, a modern and reputable software called “Forming Suite” is used, which is developed and published by FTI Forming Technologies.

#### 2.1.2.1. Optimal blank layout setup and forming feasibility

Blank layout selection process begins with importing CAD model of sheet metal bracket. Software has a wide variety of materials in its library, including the material of investigated part S355MC. Information about material are entered, such as material type and its thickness, as shown in Fig. 1.



Material Type: S355MC

Material Thickness: 3.000 mm

Select material or edit thickness

**Fig. 18.** Blank layout material selection

Based on the provided information about material, software automatically calculates the size of the unformed part, which is displayed in Fig. 19. Based on this shape, following calculations and the results of the blank layout are provided.

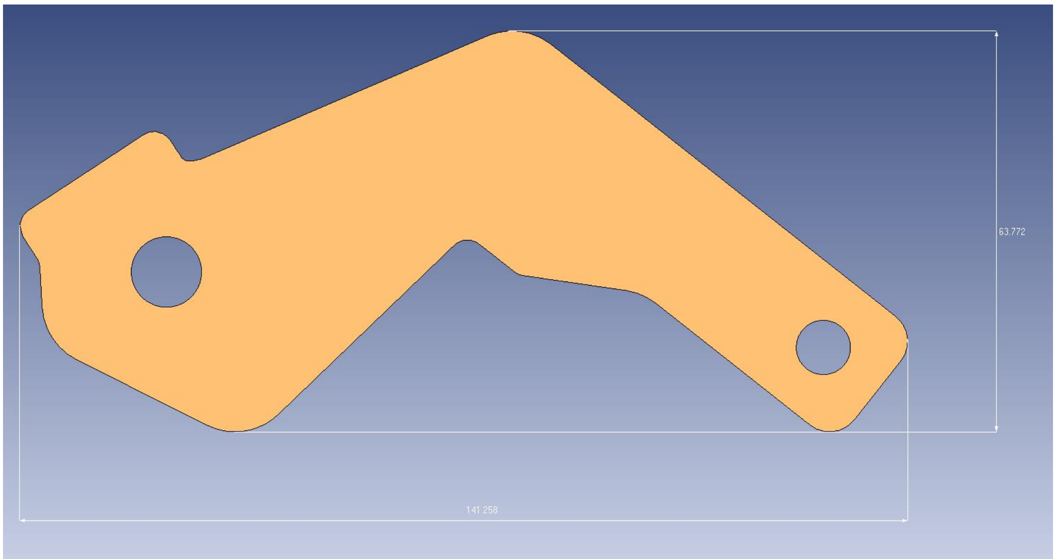
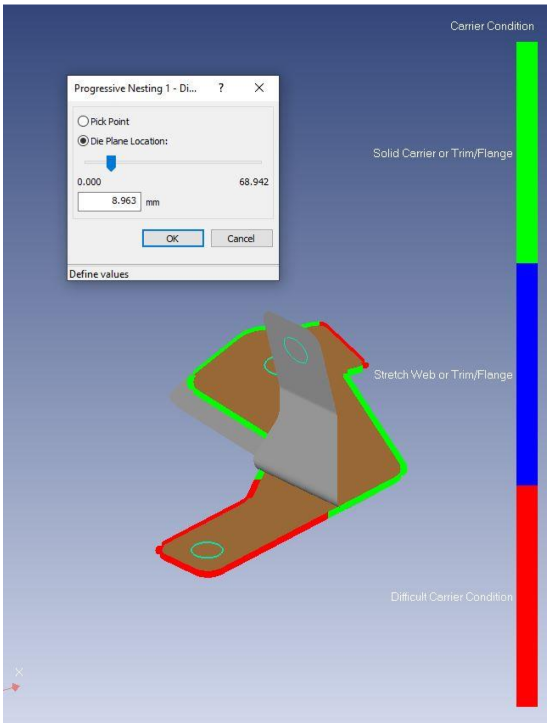


**Fig. 19.** Unformed rear muffler bracket

Also, before considering blank layout results it is important to determine where the carrying strip is connecting with the part. Segments of the part that are bent during the stamping process has to be trimmed beforehand. Segments of part outline that remain parallel to punch direction throughout all stations of progressive die should be selected for carrying. In software FTI it is possible to define formed features. Software then highlights edges that are possible for solid carrying. This can be seen in Fig. 20.



Progressive Nesting 1 - Di...

○ Pick Point

● Die Plane Location:

0.000 68.942

8.963 mm

Define values

**Fig. 20.** Part edge segments for connection with carrier strip

That sheet metal bracket formability is possible can be seen in Fig. 21. Software provides information is is safe to form particular bends for the part while evaluating its material properties. On the right side of the Fig. 21 formed part thikness is visible. Sheet metal thinning may appear in formed segments with the lowest thickness value being 2.765 mm.

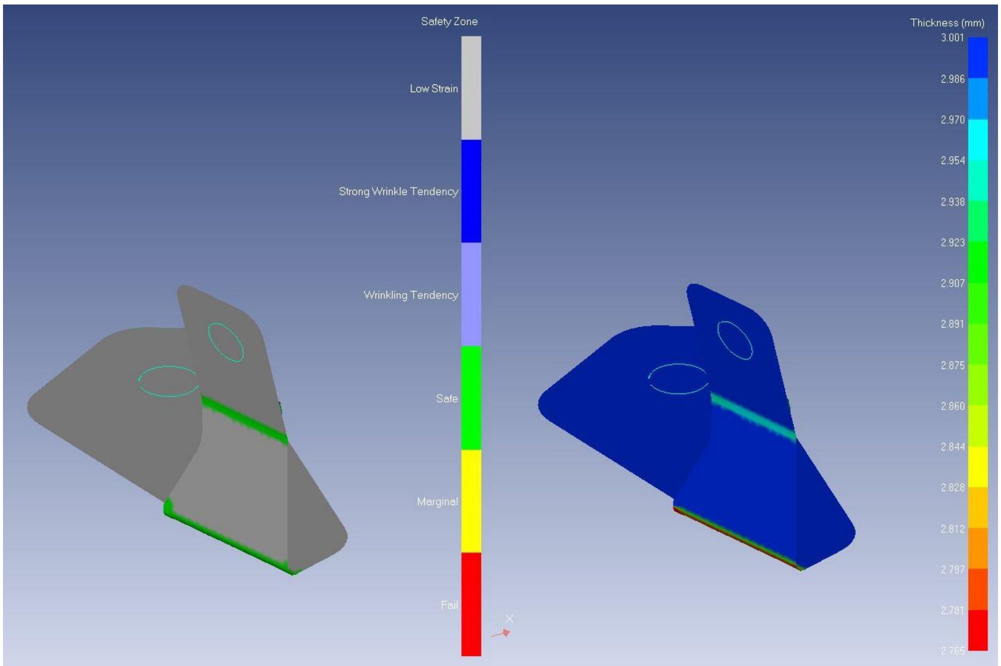


**Fig. 21.** . Left – part safety zone; right – part thickness after forming operations

Next steps require to input information about layout restrictions. Reffering to data and recommendations established by handbook of die design by Ivana Suchy [6], distance for carbon steel blanks that are of thickness of 1.1 mm or more should be around 1.8 multiplied by material thickness. Furthermore, renowned progressive die manufacturers and designers “K&K Tool & Die” recommends that the distance from part to strip edge should be around 1 to 1.25 times material thickness, when a pitch progression is lesser than two inches (around 50.8 millimeters). If the pitch progression is greater, then distance should be increased to 1.5 times material thickness. Sources also state, that this distance can be decreased for round shaped parts, because they have more material in between two blanks and only narrow to minimal recommended distance at one point, whereas rectangular parts have more separate points in between two parts where the distance is minimal. This distance is established in order to avoid material twist or wedge when the scap is trimmed. Fig. 22. displays nested blanks with main dimension names [30].

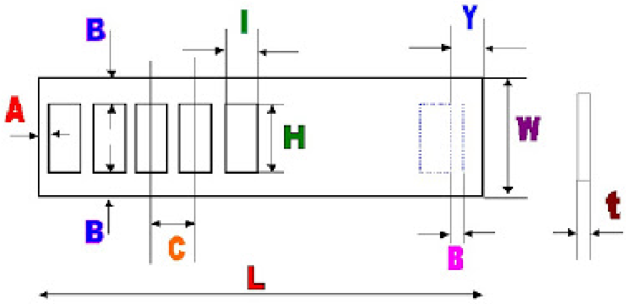


**Fig. 22.** Blank layout dimensions. A – scrap front, B – blank to coil edge distance, C – pitch progression, H – width of part, I – length of part, W – total strip width, t – material (coil) thickness, L total length of strip layout [30]

#### 2.1.2.2. Optimal blank layout results

According to reccomendations, the distances are entered to the software. It then automatically calculates and provides multiple solutions with most efficient material utilization. Table 3 shows information about most significant layouts that are described below.

**Table 3.** Results of blank layout

| Layout Number | Material Utilization, % | Type | Pitch, mm | Strip width, mm |
|---|---|---|---|---|
| 1 | 64.46 | Two up Nested Carrier | 113.37 | 121.78 |
| 2 | 64.26 | Two up Nested Carrier | 109.14 | 126.89 |
| 3 | 59.14 | One up Center Carrier | 51.02 | 147.48 |
| 4 | 58.93 | One up Center Carrier | 55.65 | 135.69 |
| 5 | 53.13 | One up Center Carrier | 64.34 | 130.17 |

Fig. 23 displays layout result with the best material utilization that maintains the information that was entered previously. However, while this layout has the best material utilization of all results, it is not feasible, because there is not possible way to add carrying strip without significantly increasing the material utilization. Carrying strip could be added to top and bottom of the strip, but this kind of solution is genrally avoided as it adds up twice as much raw material for carring as central carrying strip [31].

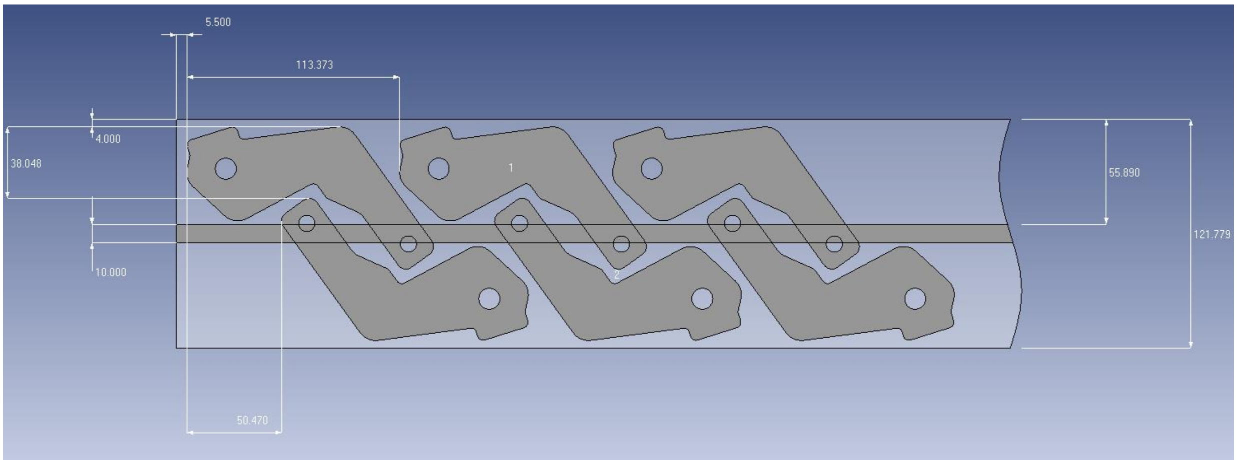


**Fig. 23.** 1st blank layout result

Second result is provided in Fig. 24. It has material utilization percentage equal to 64.26%. However such layout has the same issue as the previous one. There is no feasible way to add carrying strip. Furthermore, progressive die tonnage has to be lower than 100T. In order to completely trim contour of a single part, over 70T are required. Since in this case strip carries two parts in on pitch progression, the tonnage would double, roughly up to 140T. This would exceed 100T limitations, therefore this solution is not selected.

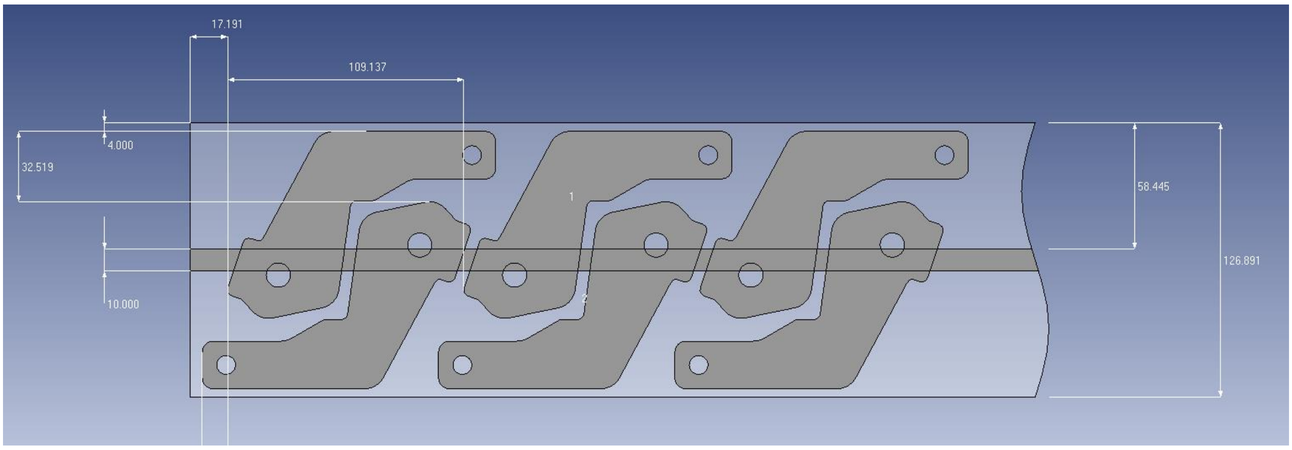


**Fig. 24.** 2nd blank layout result

Fig. 25 displays third solution, which has material utilization of 59.14%. Pitch is equal to 51.02 millimeters and strip width is 147.49 millimeters. It is similar to strip layout that is in the analysed progressive die, but the angle is adjusted for better fit of separate parts. It is possible to add carrying strip to this solution, because segments of the part that are bended are near the edges of the strip.

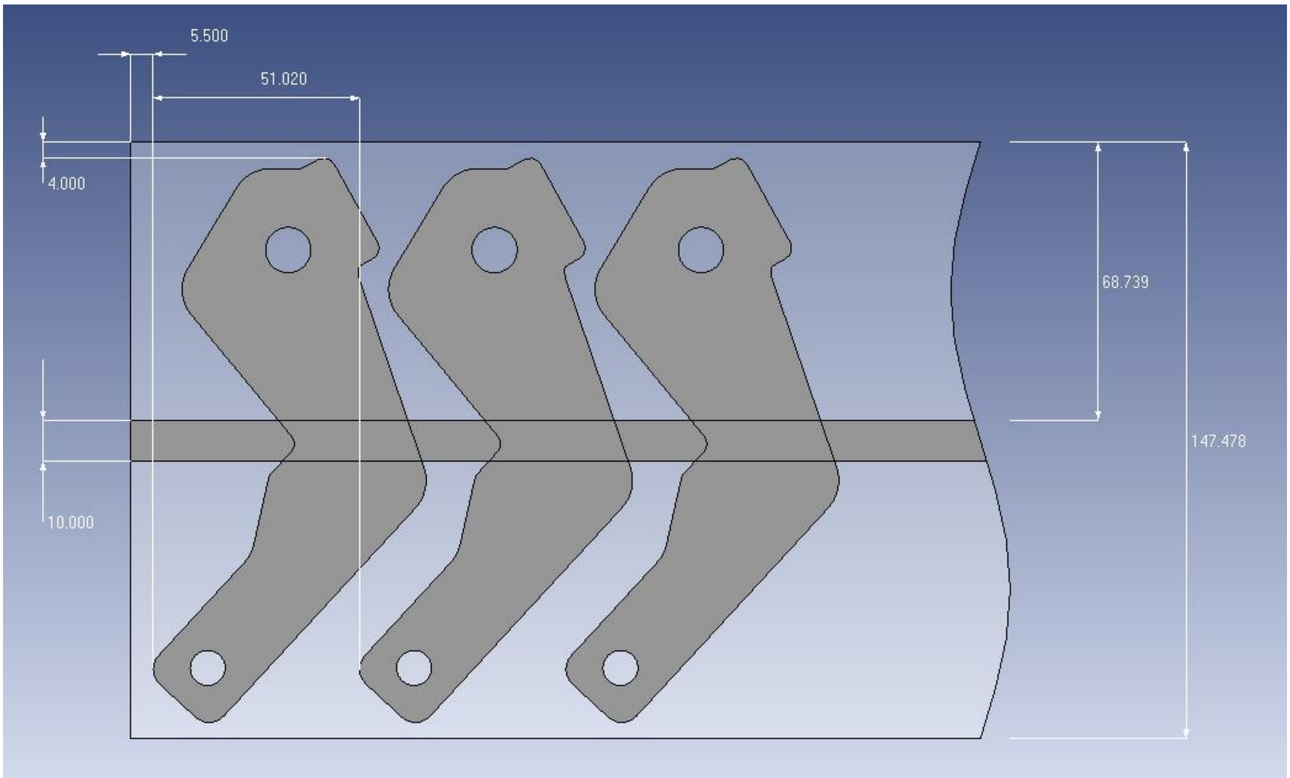


**Fig. 25.** 3rd blank layout result

A solution which is almost identical to the existing and analysed strip layout is provided in fig. 26. It has slightly smaller pitch, because the distance between separate parts have been reduced according to previously mentioned recommendations. Generally, this solution is similar to previous one, but the material utilization is slighly lower, by 0.21%. It has lower coil width, but greater pitch progression.

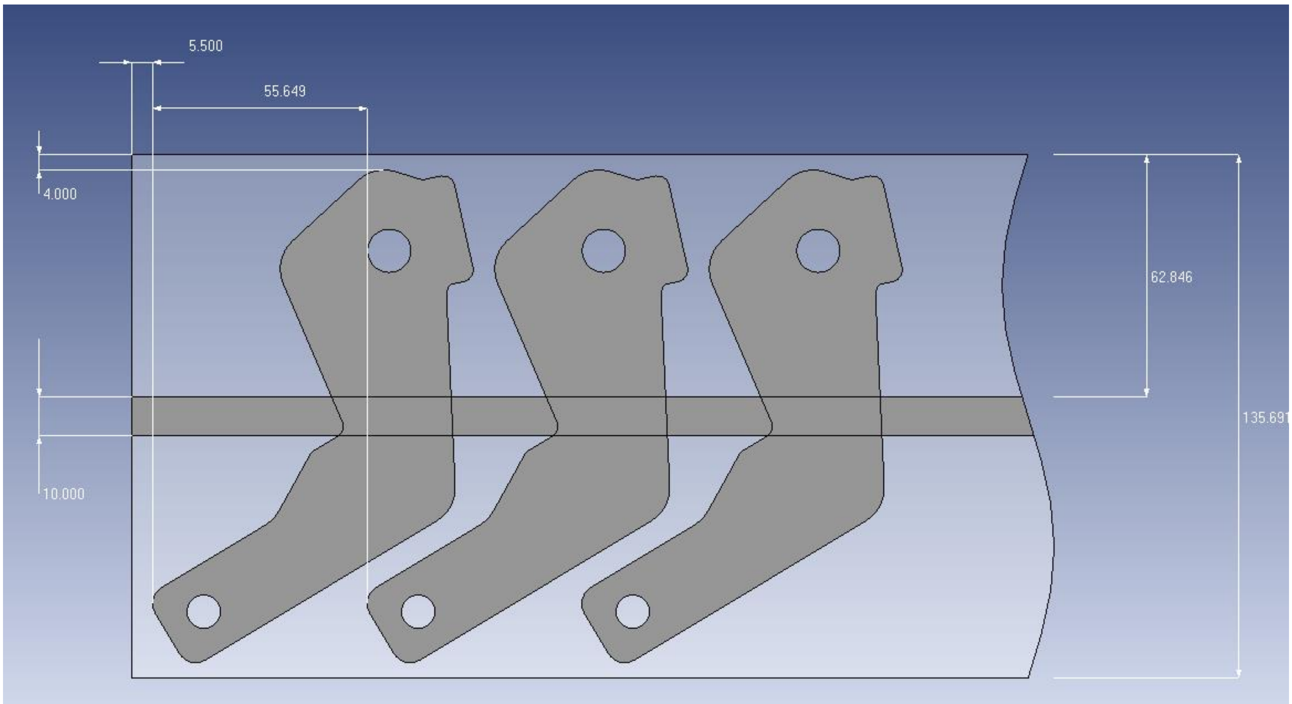


**Fig. 26.** 4th blank layout result

Lastly, fifth result is shown in Fig. 27. The material utilization is considerably lower than previous result, which is lower by 5.8%. The nesting is less efficient. Because of this, this solution is not selected. It is worth noting that the software provides more results, but they each have lower and further decreasing material utilization. For this reason other results are not analysed.

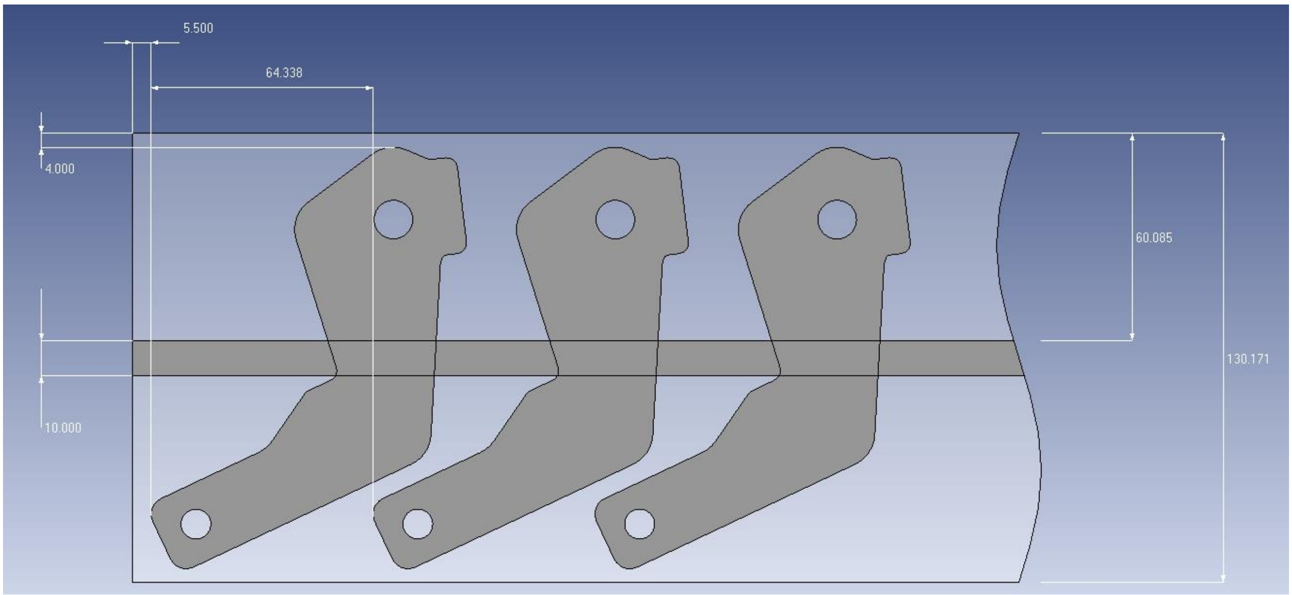


**Fig. 27.** 5th blank layout result

Since first two solutions of blank layout are not feasible, blank layout with the best material utilization out of the other three is selected, which is third blank layout. It has material utilization of 59.14%, and the parts nest well with one another.

### 2.1.3. Modernized strip layout development

With the selected blank layout, a complete strip layout is newly developed with popular CAD software SolidWorks which is extended with Logopress3 add-on, a software module specifically supporting features that makes strip layout and progressive die component design and creation easier and faster.

Following calculations are performed for strip layout:

Minimal width of the strip carrier = 1.5 × t [31]

= 1.5 × 3 = 4.5 mm

Blank area = L × W = 7904 $mm^2$ [31]

Where L – total blank length, W – total blank width

Pitch is taken from previously performed blank layout optimization and rounded up. Pitch and strip thickness are rounded up to natural numbers. This is performed to make evaluation and design and manufacturing processes easier and more streamlined. Furthermore, when even numbers are used for determining strip pitch and other component dimensions errors and inaccuracies related to number rounding are avoided. Therefore, pitch value of 51.02 is rounded up to 52 millimeters. Rounding down is sometimes used as well, but in this case, it would breach minimum distance between parts recommendation.

Part to coil edge distance = 1.5 × t [30]

= 1.5 × 3 = 4.5 mm

Distance between parts = 1.8 × t [30]

= 1.8 × 3 = 5.4 mm

Material utilization is calculated with the same formula as in previous chapter 1.4.2.

$$ŋ = \frac{n \times A}{P \times W} \times 100\% = \frac{1 \times 4418.58\ mm^2}{52\ mm \times 152\ mm} \times 100\% = 55.9\%$$

Fig. 28 displays a newly developed strip layout that has pitch progression of 52 millimeters and strip width of 152 millimeters. The minimum distance between blanks is equal to 5.67 millimeters, and part to coil edge distance is 4.21 millimeters. Contour trimming punches are split into smaller ones, because cutting huge chunks of part contour which have relatively complex shapes can result in damaged dies or punches it selves. Also, it is more simple and cheaper to remanufacture and replace punches if they break when they are segmented [32]. Part is carried near the center of the part, with bended parts being close to the edges of the coil.

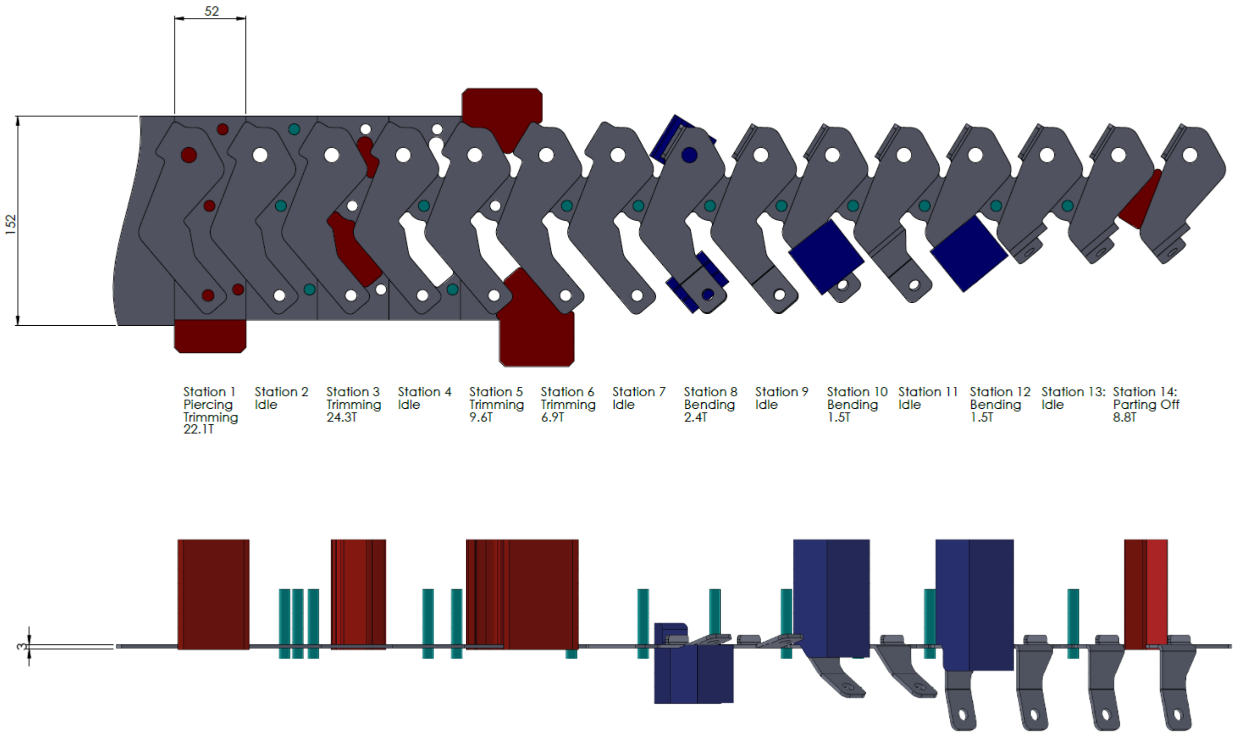


**Fig. 28.** Modernized strip layout, top and front views. Blue – forming and bending punches, teal – pilots, red – trimming and piercing punches

In comparison, original and unimproved version of strip layout is provided in Fig. 29. It has generally a lot of similarities, with slightly different part rotation within the strip. Because of this difference, original strip has lower material utilization. Distance between blanks, which is equal to 6.53 mm is also slightly bigger than in the new variant. Distance between part and coil edge is similar as in the new design and is equal to 4.43 millimeters.

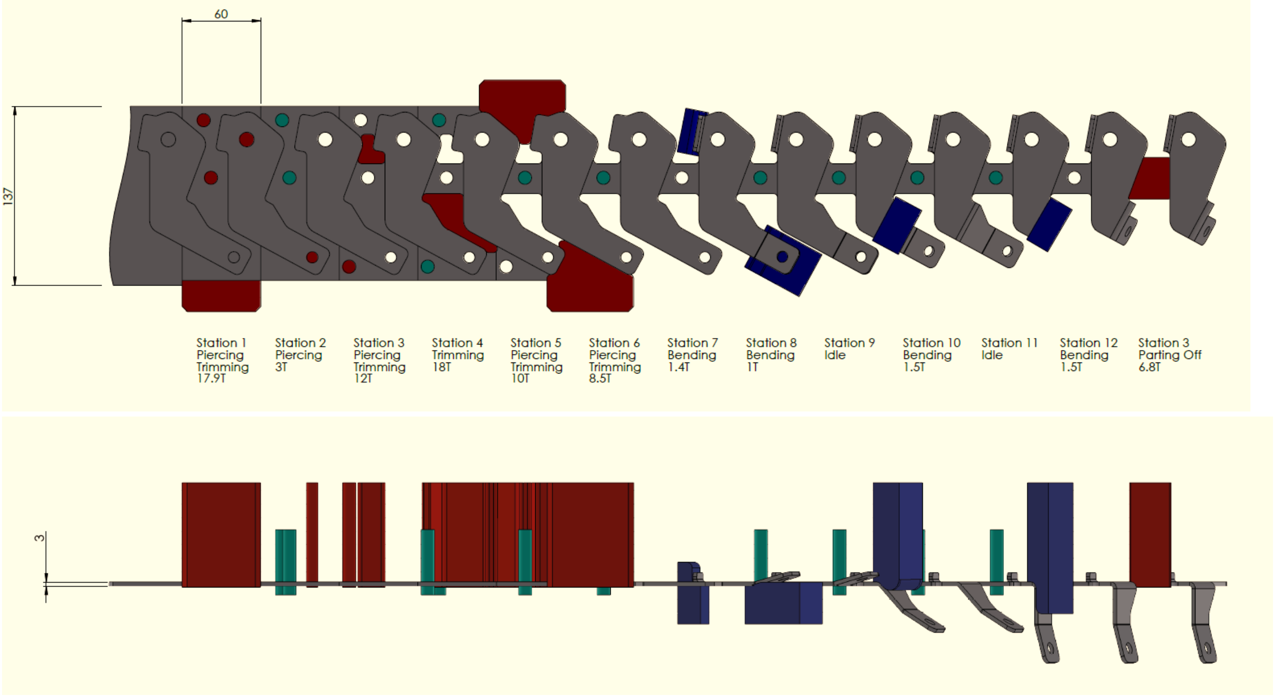


**Fig. 29.** Original, unimproved strip layout, top and front views. Blue – forming and bending punches, teal – pilots, red – trimming and piercing punches

### 2.1.4. Modernized strip layout development results

Fig. 30. shows both strip layout versions, both original and reworked. Further details of comparison are visible in table 4, where main parameters of both strip layouts are provided.

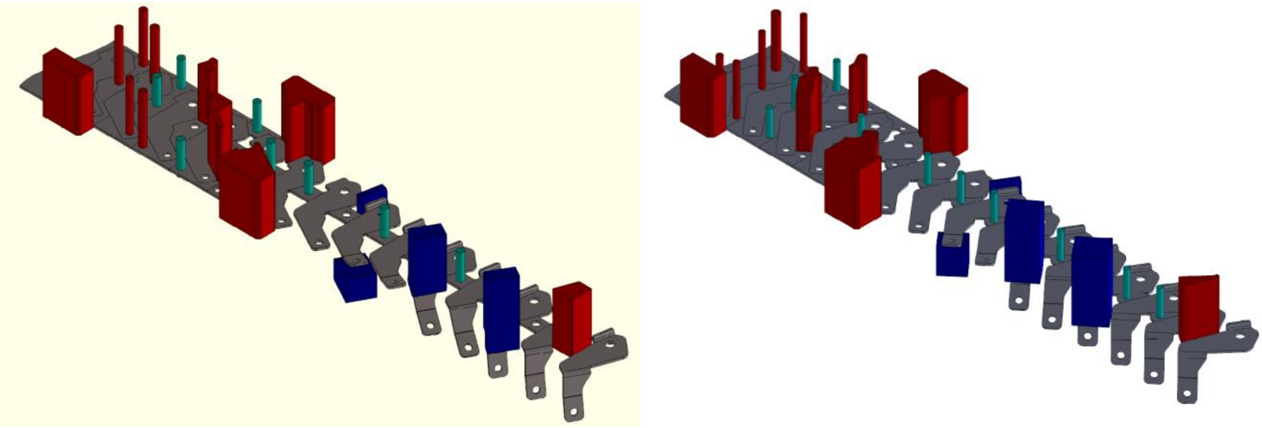


**Fig. 30.** Left – original strip layout, right – improved strip layout

Greatest improvement of modernized strip layout is improved material utilization. It has increased from 53.75% to 55.9%, which results in 2.15% increase. This means that additional 7.4 grams of raw material is not wasted with each part produced. Since yearly volume for this part is 870000 units, 6.438 tons of raw material would be saved every year until project lasts. Additionally, required stamping force is reduced from 81.6 T to 77.1 T, by 4.5 tons. This change is caused by more efficient part nesting, and shorter punch in the first station of the strip layout. The length of this punch is equal to a single pitch progression. This punch is a special requirement from manufacturer and is used for coil overfeeding prevention.

**Table 4.** Summary of strip layout results

| **Parameter** | **Old strip layout variant** | **New strip layout variant** |
|---|---|---|
| Pitch | 60 mm | 52 mm |
| Strip width | 137 mm | 152 mm |
| Strip thickness | 3 mm | 3 mm |
| Material | S355MC carbon steel | S355MC carbon steel |
| Total force required | 81.6 T | 77.1 T |
| Total force required for trimming contour | 76.2 T | 71.7 T |
| Total force required for forming and bending operations | 5.4 T | 5.4 T |
| Number of stations | 13 | 14 |
| Material utilization | 53.75% | 55.9% |
| Loss of material | 46.24% | 44.1% |
| Cutting punches perimeter | 1093.48 mm | 1028.11 mm |
| Forming punches perimeter | 588.62 mm | 588.62 mm |
| Weight of part | 104.57 (each) | 104.57 g |
| Weight of single blank | 192.35 g | 184.95 g |
| Weight of single scrap | 87.78 g | 80.39 g |
| Part surface area | 10206.43 mm$^2$ | 10206.43 mm$^2$ |

## 2.2. Modernized progressive die development

According to the developed strip layout, progressive die elements are updated using Logopress3, a SolidWorks extension for progressive die development. Main focus is on die sets because they have changed the most since previous design. Fig. 31 displays bottom plate of progressive die view with visible and invisible strip layout.

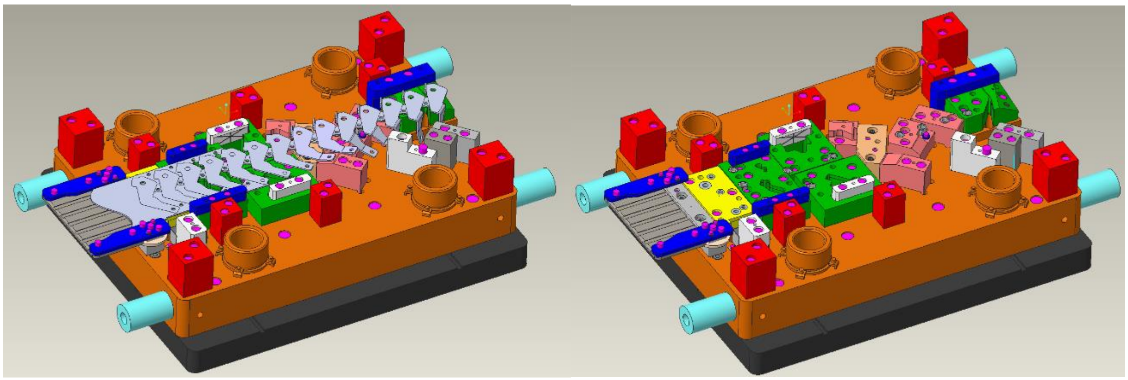


**Fig. 31.** Left – progressive die bottom plate with strip layout; right – without strip layout

Bottom plate include such components as cutting and forming dies, lifters, stop blocks, punch suports, scrap clearances. Main components for bottom plate can be seen in Fig. 32.

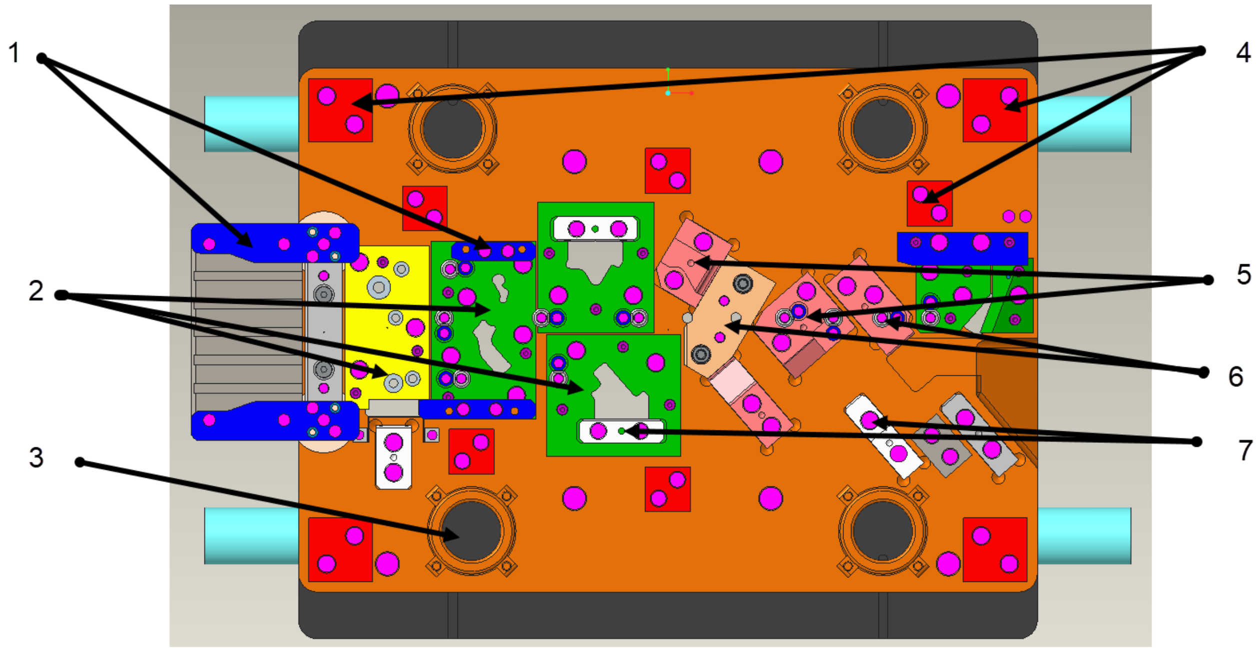


**Fig. 32.** Main component groups of progressive die's bottom plate. 1 – guiding rails (blue); 2 – cutting dies (yellow, green); 3 – guide bushing; 4 stop-blocks (red); 5 – forming dies (pink); 6- lifters (pale pink); 7 – punch supports (white)

Die sets are have clearances for punches. If die sets have improper clearances, they are more likely to wear early and may result in unwanted material burrs. General rule is to have clearances of 12% to 18% of sheet metal thickness, but it is better to base the clearance size on specific material. Table 5 provides data on several material types relating to its material thickness [33].

**Table 5.** Punch clearance table, mm [33]

| **Sheet thickness, mm** | **Material** | | |
|---|---|---|---|
| | Mild steel, up to 0.25% carbon | Aluminium | Stainless steel |
| 0.8 to 1.6 | 0.15 to 0.2 | 0.15 to 0.2 | 0.15 to 0.3 |
| 1.6 to 2.3 | 0.2 to 0.3 | 0.2 to 0.3 | 0.3 to 0.4 |
| 2.3 to 3.2 | 0.3 to 0.4 | 0.3 to 0.4 | 0.4 to 0.6 |
| 3.2 to 4.5 | 0.4 to 0.6 | 0.4 to 0.5 | 0.6 to 1.0 |
| 4.5 to 6.0 | 0.6 to 0.9 | 0.5 to 0.9 | - |

Chemical composition of steel S355MC was provided in Table 2. Maximum percentage of carbon is 0.12% for this steel grade, therefore it is considered a mild steel. Since material thickness is 3 mm, 0.3 mm clearance is used for die design.

Separate punches are grouped and punch holders are created for them. Punch plates are shown in Fig. 33.

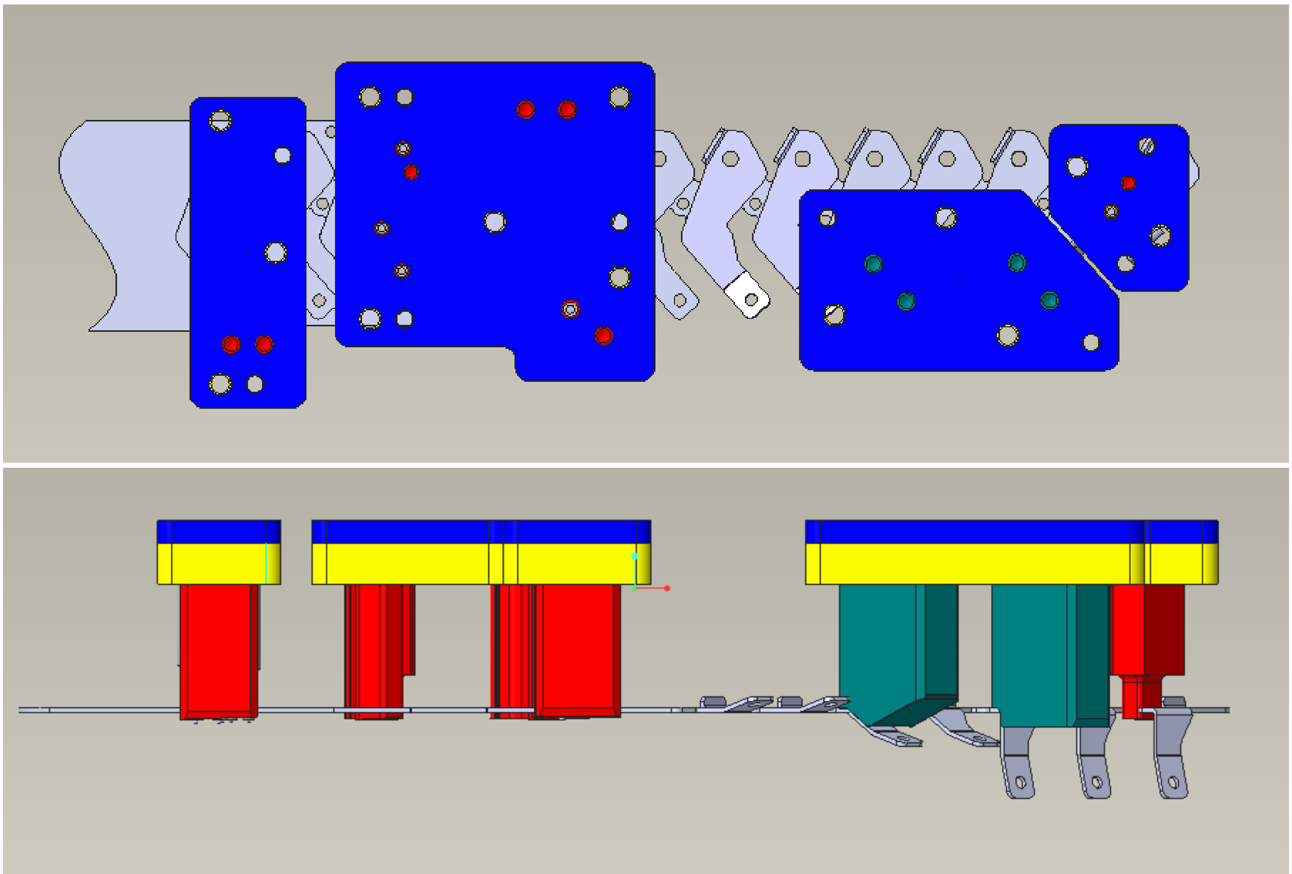


**Fig. 33.** Cutting and forming punch holder plates, top and front view. Red – cutting punches; light blue – forming punches; yellow – punch holders

Complete, modernized progressive die's top plate is shown in Fig. 34. Main components of top plate are: stop blocks, cutting and forming punches, punch holders, gas springs (to provide force for stripper pad), guide pins and stripper holder pins.

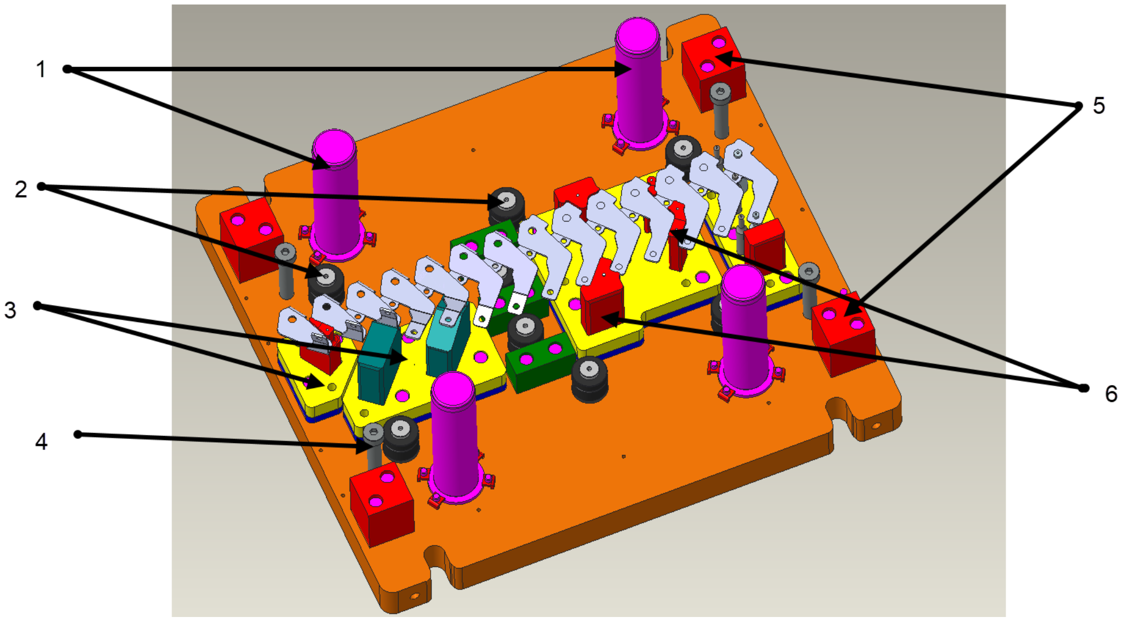


**Fig. 34.** Main component groups of progressive die's top plate. 1 – guiding pins (purple); 2 – gas springs (black); 3 – punch holder plates; 4 – stripper holder pins; 5 – stop blocks; 6 – punches (red and light blue)

Lastly, stripper pad is shown in Fig. 35. Main components of it are lower stripper plates, pilot pins and forming punches.

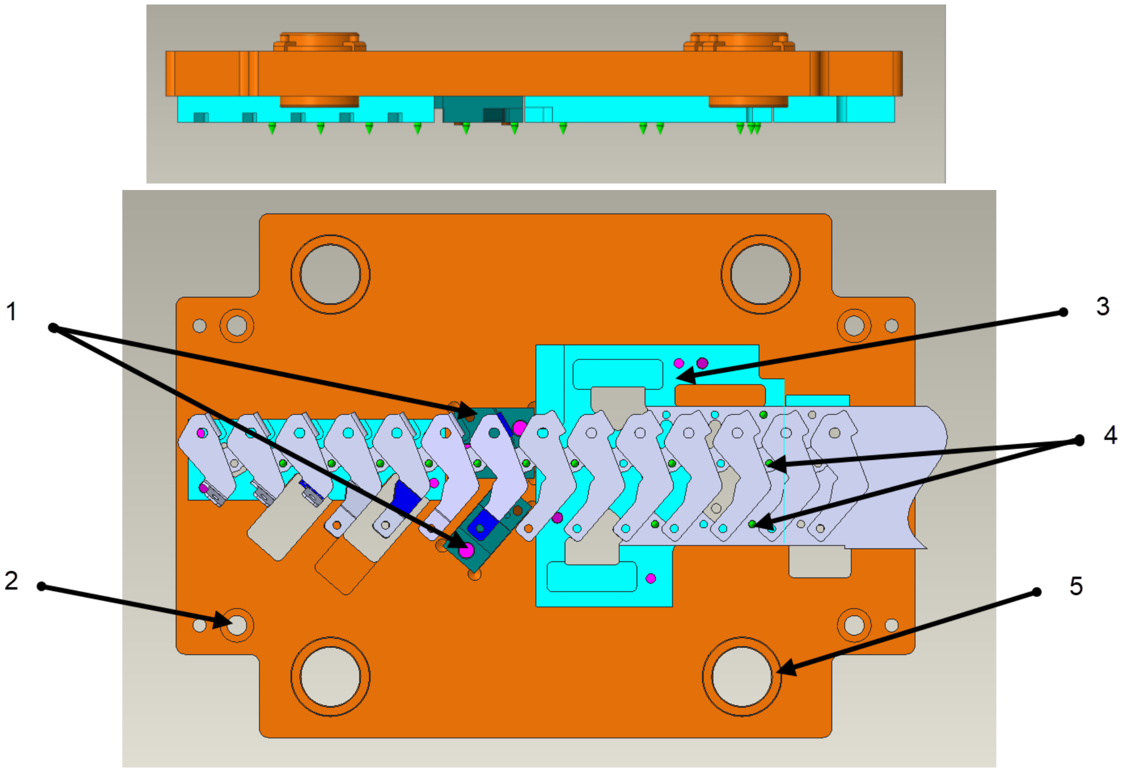


**Fig. 35.** Main component groups and elements of progressive die stripper plate, front and top views. 1 – forming punches; 2 – holes for stripper holder pins; 3 – lower stripper plates; 4 – pilot pins; 5 – guide bushing

Stripping force consists of generally around 10% of total progressive die shear force. Since two of the bends are formed by stripper pad as well, their force has to be added to general stripping force [34].

$$\text{Stripping force} = 0.1 \times \tau + F_s \qquad [34]$$

Where,

$\tau$ – shear force, expressed in tons

$F_s$ – bending force (for bends that are formed with striper pad, Fig. 36), taken from strip layout drawing, bending and trimming forces are automatically calculated for each punch

$= 0.1 \times 77.1 + 2.4 = 10.11$ ton

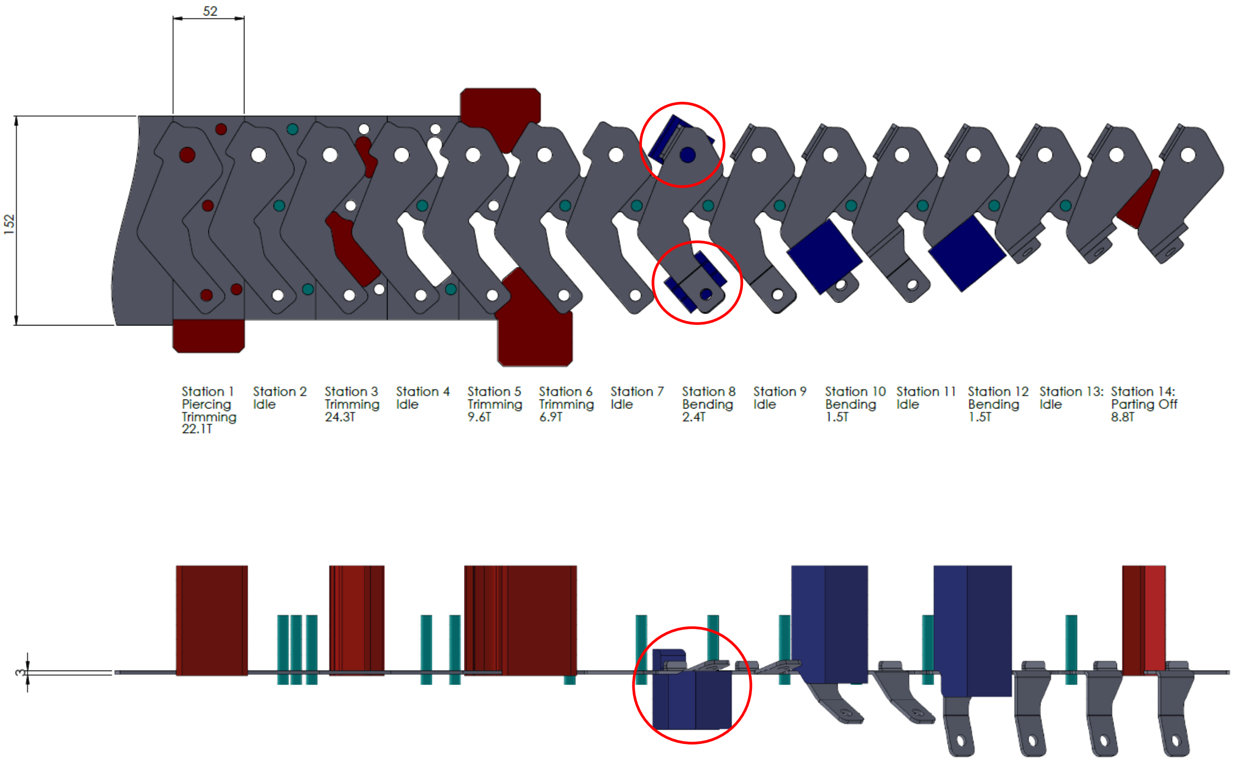


**Fig. 36.** Part flanges that are formed with stripper pad, marked with red circles

Approximately 10 ton or 98000 N force has to be provided for stripper pad. Such springs are selected from gas spring provider in Europe – Kaller [35].

In accordance, seven X 1000-019 gas springs are selected from their online catalog, drawing with main parameters are provided in Fig 37 and Table 6.

These springs has 14000 N force each at full stroke.

Number of springs required = Force required for stripper pad / spring force =

98000 / 14000 = 7 springs

Seven of the selected springs are required for stripper pad.

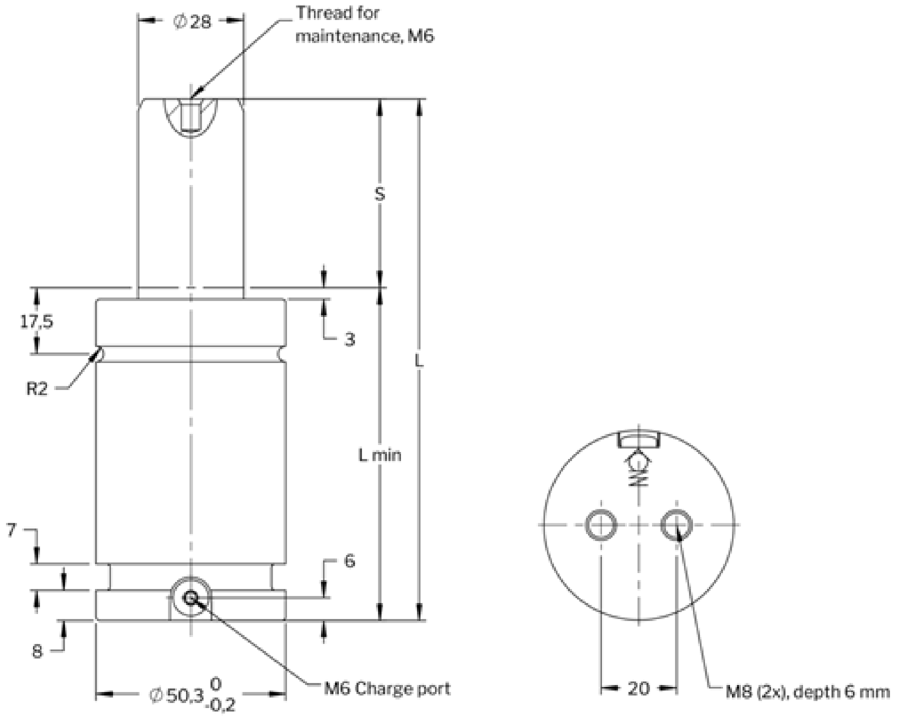


**Fig. 37.** Kaller X 100-019 gas spring. L – 76 mm; L min – 57 mm; S – 19 mm [35]

**Table 6.** Kaller X 100-019 gas spring attributes [35]

| **Spring attribute** | **Value** |
|---|---|
| Stroke (mm) | 19 mm |
| Force at full stroke | 14000 N |
| Height, unsprung | 76 mm |
| Height, sprung | 57 mm |
| Gas vol. | 0.04 l |
| Weight | 0.56 kg |

Main parameters of developed progressive die are provided in Table 7.

**Table 7.** Progressive die attribute comparison

| **Progressive die attribute** | **Old progressive die, value** | **New progressive die, value** |
|---|---|---|
| Lengh | 840 mm | 790 mm |
| Width | 685 mm | 700 mm |
| Height, when die is closed | 388 mm | 388 mm |
| Pitch | 60 mm | 52 mm |
| Working tonnage | 100 T | 100 T |
| Weight, approximate | 1.1 T | 1.1 T |
| Stripper pad stroke height | 16 mm | 16 mm |
| Minimum stroke height | 220 mm | 220 mm |

## 2.3. Conlcusions on progressive die modernization

In this chapter, a modernized progressive die and its strip layout are developed, and its main parameters provided. For the conclusion of this chapter, following conclusions are stated:

1. After blank layout optimization methods were applied, progressive die increased its raw material utilization by 2.15% and increases its sustainability. It equals to 7.4 g of carbon steel saved for each sheet metal part produced. Moreover, required stamping force is reduced from 81.6 tons to 77.1 tons. Such reduction might result in slight increase of component lifespan and reduce component wear. Design of strip layout remains similar, but has more efficient part nesting. Width of the coil has changed from 137 mm to 152 mm, and pitch progression has changed from 60 mm to 52 mm.
2. According to newly developed strip layout, progressive die has been designed. It consists of three main assemblies that are common to most progressive dies: top plate, bottom plate and stripper pad. Required forces for stripper pad are calculated and specific gas springs are selected.

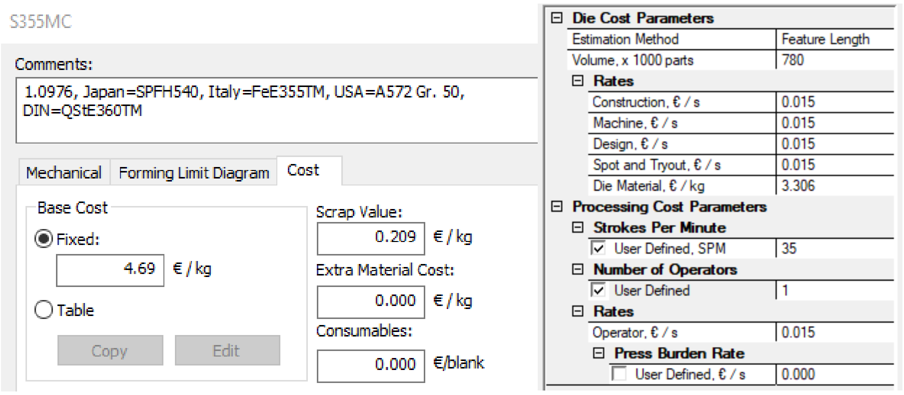
## 3. Project cost calculations

Progressive die cost can be estimated by using modern software FTI Forming Suite, which can automatically estimate progressive die cost based on part material and part features.

Material price for 3 mm thickness hot rolled coil of grade S355MC steel, is $570 per metric ton, which equals to 469€ per ton [36].

According to online scrap cost database “iscrapapp”, steel scrap price is $205 per ton. Converted to euros it is approximately 168.72€ [37]. This information is entered to FTI forming suite.

Since year 2017 Forming Suite is used in this research default price values are outdated. Therefore, this new price data is entered to software, to make price estimation more accurate, as shown in Fig. 38. Die cost parameters are edited as well, with annual volume of 780000 and 35 stroke per minute parameters defined. Other parameters are left unedited, as it is standard average rates that already exist within software’s database. Feature length cost estimation method is selected as it is most suitable for progressive dies that has strip layouts already developed. Other estimation methods are blank area and blank perimeter methods, but they are less accurate and generally more suitable for blanking dies.



S355MC

Comments:

1.0976, Japan=SPFH540, Italy=FeE355TM, USA=A572 Gr. 50, DIN=QStE360TM

Base Cost

● Fixed: 4.69 € / kg

○ Table

Scrap Value: 0.209 € / kg

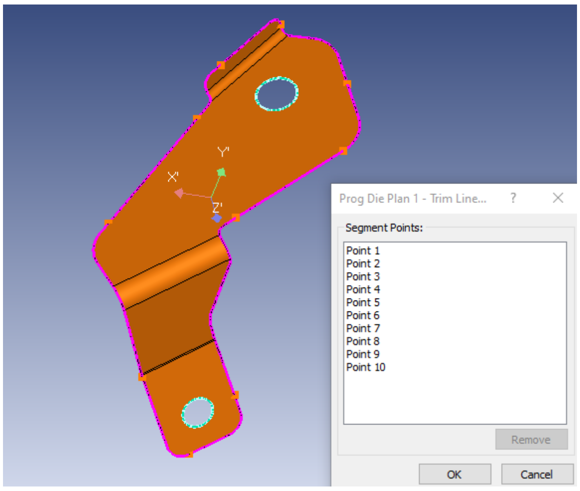
Extra Material Cost: 0.000 € / kg

Consumables: 0.000 €/blank

| | |
|---|---|
| ⊟ **Die Cost Parameters** | |
| Estimation Method | Feature Length |
| Volume, x 1000 parts | 780 |
| ⊟ **Rates** | |
| Construction, € / s | 0.015 |
| Machine, € / s | 0.015 |
| Design, € / s | 0.015 |
| Spot and Tryout, € / s | 0.015 |
| Die Material, € / kg | 3.306 |
| ⊟ **Processing Cost Parameters** | |
| ⊟ **Strokes Per Minute** | |
| ☑ User Defined, SPM | 35 |
| ⊟ **Number of Operators** | |
| ☑ User Defined | 1 |
| ⊟ **Rates** | |
| Operator, € / s | 0.015 |
| ⊟ **Press Burden Rate** | |
| ☐ User Defined, € / s | 0.000 |

**Fig. 38.** Material and die cost parameters

In order to make estimation more accurate, part outline is defined into segments, as shown in Fig. 39. These segments correspond to cutting punches of the die. With the segments assigned, software can perform calculations on length of the punches.

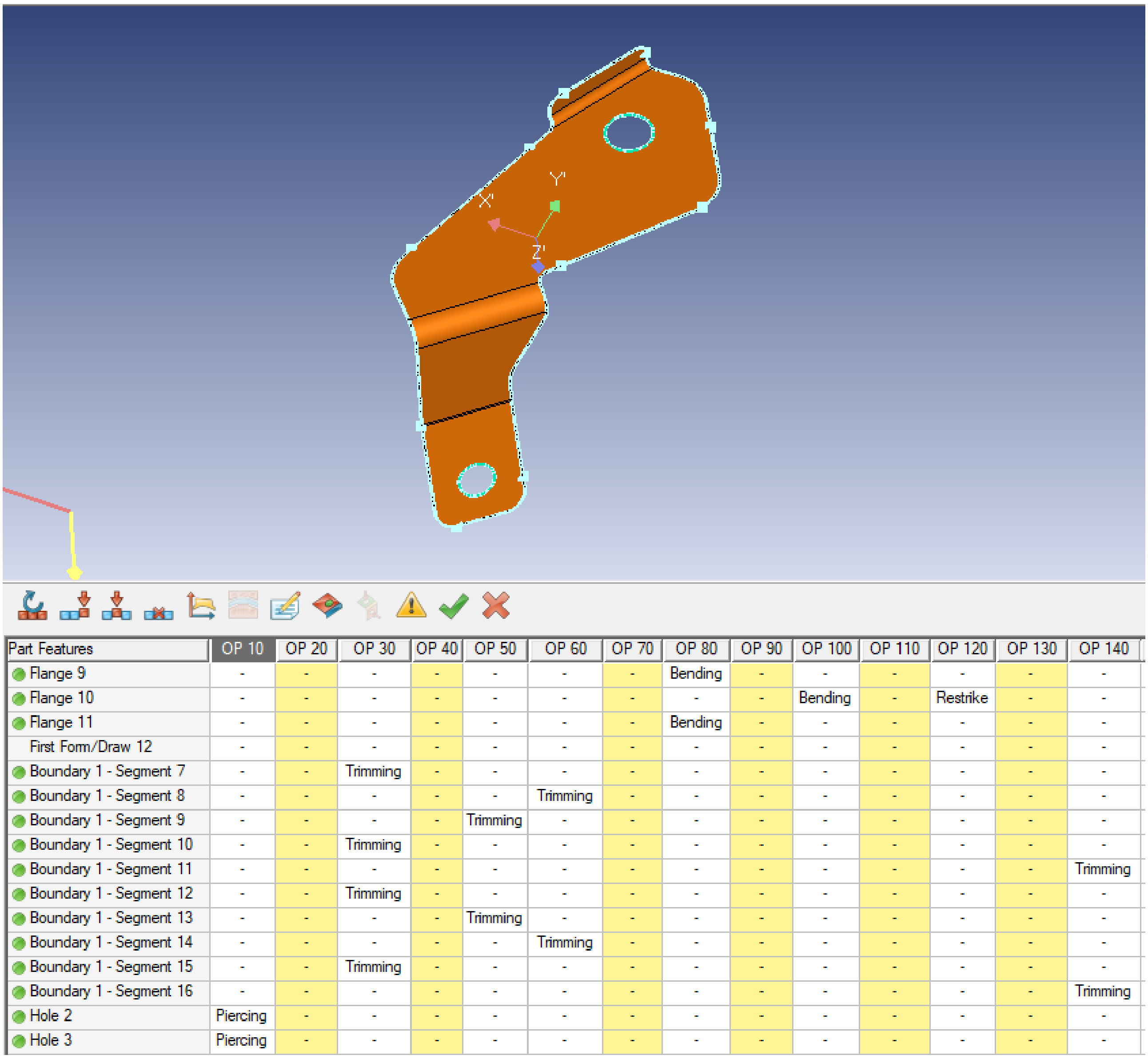


Segment Points:

Point 1
Point 2
Point 3
Point 4
Point 5
Point 6
Point 7
Point 8
Point 9
Point 10

**Fig. 39.** Part trimming segments

Further steps for cost estimation set up are definement of features. All bending and trimming features of strip layout are defined and then operation plan is created. Detailed operation plan is provided in Fig. 40.



| Part Features | OP 10 | OP 20 | OP 30 | OP 40 | OP 50 | OP 60 | OP 70 | OP 80 | OP 90 | OP 100 | OP 110 | OP 120 | OP 130 | OP 140 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flange 9 | - | - | - | - | - | - | - | Bending | - | - | - | - | - | - |
| Flange 10 | - | - | - | - | - | - | - | - | - | Bending | - | Restrike | - | - |
| Flange 11 | - | - | - | - | - | - | - | Bending | - | - | - | - | - | - |
| First Form/Draw 12 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 7 | - | - | Trimming | - | - | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 8 | - | - | - | - | - | Trimming | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 9 | - | - | - | - | Trimming | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 10 | - | - | Trimming | - | - | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 11 | - | - | - | - | - | - | - | - | - | - | - | - | - | Trimming |
| Boundary 1 - Segment 12 | - | - | Trimming | - | - | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 13 | - | - | - | - | Trimming | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 14 | - | - | - | - | - | Trimming | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 15 | - | - | Trimming | - | - | - | - | - | - | - | - | - | - | - |
| Boundary 1 - Segment 16 | - | - | - | - | - | - | - | - | - | - | - | - | - | Trimming |
| Hole 2 | Piercing | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Hole 3 | Piercing | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Fig. 40.** Progressive die operation plan

With all of the supplied information, Forming Suite software then performs cost estimation and predicts main features (such as die sizes) of the progressive die. The results are provided in Table 8. Total progressive die cost is estimated as 15913.43 euros. Die cost per part is 0.02€ and processing cost per part is equal to 0.106€. With this information further calculations can be performed.

**Table 8.** Progressive die estimation results

| **Progressive die attribute** | **Value** |
|---|---|
| Process | Progressive |
| Number of cam units | 0 |
| Die load | 629131.741 N |
| Die energy | 1.39 kJ |
| Severity level | Low |
| Number of direct holes | 2 |
| Number of trim segments | 10 |
| Total trim length | 360.01 mm |
| Number of flanges | 4 |
| Total flange length | 115.61 mm |
| Die size, front to back | 862 mm |
| Die size, left to right | 884 mm |
| Minimum stroke | 218.432 mm |
| Shut height | 369.86 mm |
| Strokes per minute | 35 |
| Press burden rate | 0.047€ per second |
| Number of operators | 1 |
| Total die weight | 1382 kg |
| Total die cost (estimation on feature length) | 15915.49€ |
| Die cost per part | 0.02€ |
| Processing cost per part | 0.106€ |
| Parts per stroke | 1 |

## 3.1. Project pay back period

With the data from this estimation, calculations of payback period can be calculated. First, saved material per each part manufactured is calculated.

Weight of old blank = 192.35 g, taken from Table 3.

Weight of new blank = 184.95 g

Saved material per part = Weight of old blank - Weight of new blank

= 192.35 – 184.95 = 7.4 g

Now, since yearly production volume is known, how much material is saved per year is calculated.

Saved material per year = saved material per part × yearly volume =

= 7.4 × 780000 = 5772000 g = 5.772 ton

This amount of material worth in euros can be calculated.

Saved costs per year = saved material per part × material cost =

= 5.772 × 469 = 2707.07

Payback period = progressive die cost / saved costs per year =

15915.49 / 2707.07 = 5.88 years

### 3.2. Conclusions of project cost calculations

After performing calculations on project costs, following statements are concluded:

1. For progressive dies of medium to high complexity, which has hundreds of different componets cost estimation can be a difficult progress, if approaching with standard cost estimation methods. Luckily, cost estimation is more simple when using modern software such as FTI Forming Suite, Autoform or others which has cost estimation modules included in it. In this research FTI Forming Suite cost estimation based on feature length is used. Features of analysed part, basic values of raw material, labor and other costs were defined and progressive die operation plan was created. With this information software then estimates the total cost of progressive die, which was equal to 15915.49€, including material, design, manufacturing, assembly and other costs. Using this method there is no need to assign material and processing costs to each part.
2. With estimated total progressive die costs project pay back time period is calculated, if existing progressive die was replaced with the improved one, which is equal to 5.88 years. After this period, such project would start generating profit. This duration would decrease in three cases: if production volume would increase, if progressive die would be redesigned to have even better material utilization or if raw material price would increase.

## Recommendations

For further research, following recommendations are provided:

1. Apply additional progressive die modernization methods, trim line optimization.
2. Perform additional calculations on progressive die component geometry and feasibility
3. Set up detailed progressive die simulation to see how the progressive die would operate under real conditions.

# Conclusions

With the performed research of progressive die modernization, following statements are concluded:

1. Progressive die structure is analysed. Progressive dies have generally complex structure and are made of hundreds of different parts and sub-assemblies. Main sub-assemblies are top and bottom die plates and stripper pad. Strip layout acts as a central design piece of progressive die, as it determines the most important progressive die attributes: pitch progression, part nesting, number of stations, size of progressive die and others. Therefore, choices taken in strip layout design phase are very important, especially when progressive die structure complexity is high.

   Main modernization methods are application of trim line and blank layout optization. The latter is a staple modernization method as it has major influence on raw material utilization efficiency, because even small improvements in layout may result in significant savings in manufaturing costs. However, sometimes solutions with best material utilization are not the best solutions overall, as other factors such as feasibility, additional manufacturer requirements, tolerance limits and other restrictions have to be considered.
2. Progressive die and its strip layout has been modernized by applying blank layout optimization method, as it heavily impacts material utilization efficiency. Material utilization has increased by 2.15% and has became more sustainable. 7.4 grams of raw material, carbon steel is saved per each stamped sheet metal bracket. Furthermore, required stamping force reduced by 4.5 ton, this may lead to prolonged die lifespan and reduced component wear. Strip layout design has remained similar, but with more efficient nesting of parts. Coil width has increased from 137 mm to 152 mm, while pitch has reduced from 60 mm to 52 mm.

   Based on strip layout, progressive die design is created and required forces for stripped pad are calculated and suitable gas springs are selected.
3. For this research, FTI Forming Suite‘s cost estimation based on feature length was performed. With the entered initial data, such as part features, operation plan, labor costs among others, software provided an estimated value of total progressive die cost – 15915.49€. Such estimation methods are used when there are hundreds of components with different materials and costs.

   Pay back period is calculated, if the existing progressive die would be replaced with newly manufactued, modernized progressive die. It equals to 5.88 years, which is quite lengthy time frame. If the total project duration for stamping this specific sheet metal part is longer than the calculated result, such solution might be considered. It is worth noting, that this duration could become shorter, if raw material price or production volume would increase. Additionally, progressive die could be redesigned further to improve material utilization even more.

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# Appendices

## Appendix 1. Certificate of participation in International Young Researchers Conference “Industrial Engineering 2021”

International Young Researchers Conference

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## Certificate

This certificate confirms that

**Simonas Leonavičius**

attended in International Young Researchers Conference
“Industrial Engineering 2021” and published the paper

**Progressive Strip Layout Modernization for Increased Material Utilization**

in the conference notification material

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