MODULAR CONCEPTION FOR HIGH SPEED CUTTING MACHINES USING LASER, PLASMA OR WATER JET TECHNOLOGIES

Technical university – Sofia, Bulgaria

Abstract: This study aims to preview a modular conception of building high speed sheet metal cutting machines using three different sources – laser, plasma and water jet. The modular principle of building opportunities to develop a wide variety of variants allowing different workpiece parameters with addition to the usage of the specified cutting sources, covering a range of machines. Presented project focuses on a product created using virtual prototyping technology showing its advantages in the development of multiple variants design. The result is a highly competitive product, which allows to answer customer requirements for various options with minimal expenses for manufacturing technologies and finally gives a sustainable market solution.

Keywords: MODULAR DESIGN, SHEET METAL CUTTING, LASER, PLASMA, WATER JET, VIRTUAL PROTOTYPE

1. Introduction

The industrial practice face a number of different technologies and machines in high speed cutting sheet metal with lasers, plasma or water jet pressure (3, 4, 10).

There are different criteria for sheet materials cutting systems classification.

- Size of work area:
  - small;
  - middle;
  - large.

- In performance:
  - standard;
  - high precise.

- The number of controlled axles: 2D or 3D, (9).

Research and development of high speed systems of the highest technological level and the other at a relatively cheap price levels, with high technical performance and available to SMEs (small and medium enterprises) is especially topical.

A large number of competing manufacturers and analysis of their products requires the implementation of low-cost fully functional technical solution based on modular system characterized by:

- Simplified structure with extensive use of standardized and ready for purchase items (6);
- Provide high working speed (20m/min) and positioning speeds (50m/min) at very good dynamic accelerations over 1G (7, 10, 11);
- Using the highly reliable CNC control system for mid-price range in order to better acceptance of the product to foreign markets and ease of maintenance and servicing;
- Consistency management system with popular CAD formats to automate the creation and technological preparation of CNC programs (3, 9);
- Optional incorporation of the axes C and B, to produce a detailed contour edge chamfer shaping for subsequent welding.

2. Modular strategy for design

Need to implement modular design strategy of building a system for high precision cutting of sheet material (8) is related to continuously changing conditions and increasing demands of modern production - increasing the range of products reducing time-to-market and shorten the period of renewal of the products to maintaining their high technical level and increasing requirements for quality. The choice of economically cutting system composition for different conditions of production are crucial. For manufacturers of cutting systems need continuous development and utilization of machines, most satisfying customer needs by increasing the technical level of reliability and minimal loss of time for design and construction (2, 12).

Modular conception

These requirements most effectively meet modular strategy of design and composition: on the basis of a limited set of separate functional and structural elements completed - modules to build most systems meet specific requirements with short delivery times and predictable working behavior.

The modular system offers optimum technology choice for different types of machine cutting (laser, plasma, water jet high pressure) and for different sheet materials (steel, light materials, composites, stone, etc.).

The modular principle of design in computer-aided design of machine tools differs substantially from traditional approaches to design. (1, 5) The primary task of synthesis, however, is offset by an analysis of features and capabilities of the resulting packaging system (consistency, rationality, etc.), While synthesis of type modules shall be based on empirical experience and statistics. Evaluation of the models is also difficult and largely subjective. Computer realization of this principle gives ample opportunity for full realization variant, and the correct evaluation of decisions and selection of optimal under the following circumstances:

- Managing systems can be unified, leading to increased reliability, low cost and which is especially important - facilitated training, preparation and performance at work of specialists dealing with programming and setting up systems;
- To date, in need of transition from one technology to another (for a instance from laser to plasma or water jet with high pressure) is often necessary to buy separate expensive systems at a time when changing technology may become redundant or be used as processing at a certain time. With this modular system is avoided by changing the source and only some modules of the system. Alternatives are going back in time and technology (cutting torches or individual complete systems);
- They covers problems of flexibility and dynamism of the choice of the technological process, thus introducing less waste technologies, environmental processes and greater profitability;
- High performance and accuracy of the systems - based on experience and planned to use the most modern tools for design and simulation is quite realistic to achieve very high performance.
in terms of speed, agility and precision of the structure of systems that will align to the world's leading models.

The new speed and precise cutting processes provide optimal and minimal technological waste, and hence significant savings in raw materials.

Maximum automation of process of cutting and automation of loading/removal of materials and ready components of the working plot area will improve the quality of working conditions and will reduce side time.

The modular system is complicated enough product to require cooperation of several specialized companies at all stages of research, design and production. This is shown on the block diagram on figure 1.

![Fig. 1 System form](image)

The concept is aimed at two audiences:

- large and medium-sized manufacturing companies are used high throughput laser plasma or water jet machines for its own needs;
- small businesses, etc. "Job-shop", providing services for other companies – needs more flexibility than productivity.

All these features are considered in conceptual and “space compound” build a modular system.

**Specific requirements**

From the condition for modular design of engineered machinery necessary arrangement chosen to satisfy the requirements for each of the machines, while having to meet the specific conditions of the process. Which means you should be able to work with plasma, laser and WATER-JET source to allow for automatic switching of preparations have bath for fire flow and sedimentation of the abrasive in WATER-JET machine can perform cutting a water curtain in cutting, have better access to work area filling with blanks and control others.

Meet all requirements have to cover a detailed analysis of various options, combined with extensive engineering experience.

3. **Definition of common technical parameters of the modular system**

Made on the basis of technical study of the machines for high precision cutting of sheet materials, using high-tech sources - Laser, plasma and water jet concludes that there is no single system where complete unification is possible.

Due to the specifics of each of the processes of cutting, there are elements and subsystems that are common regardless of the source and cutting the size range of cutting, as well as those that are unique to a given case.

The presence of composite modular system allows the facility to be configured specifically according to customer requirements with minimal changes and reconfiguration.

The main elements and composition of the modular system (also shown on figure 2) are:

- **Mechanical subsystem:**
  - body of the machine;
  - Transverse machine beam;
  - Drive;
  - Protection covers and waste extraction system;
  - Other;
- **Transport system:**
  - Pallet (changing) station;
  - Pallets;
- **CNC System**
- **Source (Laser/Waterjet/Plasma).**

![Fig. 2 Modular system composition](image)

**Definition of mechanical subsystem**

Mechanical subsystem consists of the next main components:

- Body of the machine;
- Transverse machine beam;
- Drive;
- Protection covers and waste extraction system;
- Others:
- Aspiration system;
- Bath - when the cutting machine water jet and plasma machines operating with a protective water environment;

Dimensions of the machine depend on the size of the workpiece. On the other hand the dimensions of blanks depend on the dimensions of standard sheet materials.

Based on these dimensions are separated several sizes of machines:

- 1500 mm x 3000 mm - enables workpiece dimensions 1000 x 2000; 1250 x 2500, 1500 x 3000;
- 2000 mm x 3000 mm - enables workpiece dimensions 1000 x 2000; 1250 x 2500, 1500 x 3000, as well as simultaneous processing of three sheets of the most popular gauge 1000 x 2000;
- 2000 mm x 4000 mm - makes it possible to handle all preparations with less than or equal to the nominal size, and combined processing of multiple sheets at a time;
- 2000 mm x 6000 mm - makes it possible to handle all preparations with less than or equal to the nominal size, and combined processing of multiple sheets simultaneously.

Working bodies backing the movement along the axes X, Y must move to comply with these dimensions. Movements in the Z axis and is positioned to be consistent with the thickness of the workpiece.
In water jet and plasma machines and machines working on combined method, where a bath to avoid excessive complexity of the structure shall be defined only two gauge: 1500 mm x 3000 mm and 2000 mm x 3000 mm.

Main frame:

As seen from the above classification made based on the dimensions of the processed sheet blanks, there are three options in length. To avoid the presence of many modifications are elected for a standard length of the body - 3000, and other lengths are processed through repositioning, performed by an automated pallet station.

The main advantages of this packaging are:

- propulsion and guidance components and optical ways (with laser) will be in smaller lengths, which reduces significantly their cost as fall within the lower (standard) price range;
- body machine with smaller dimensions, allowing for easy transport and easier handling in its manufacture.

This version of the work has two disadvantages:

- having a fixed device offer the position;
- the possibility of errors from mismatch of the two cuts - but we believe that when large sheets are processed, accuracy requirements are relatively low and the processing of smaller parts, they are grouped so that no cut in the area of repositioning.

In the described packaging system of the body is unified modular system for different lengths are influenced only by the width, which is designed for a specific machine. According widths is: 1500 mm; 2000 mm.

Due to greater demands for precision in laser cutting machine, unlike the plasma cutting machine and water jet, metal structure needs to be more stable and high vibration resistance. From this perspective also has two options:

- rigid mechanical structure - used in laser machine;
- lightweight mechanical structure - used machines and plasma cutting water jet.

The classification of the body as part of the mechanical subsystem is depicted in Figure 3, and the options involving a given model are shown in Tab.1.

**Table 1: Modular system transversal beam design variants**

<table>
<thead>
<tr>
<th>Source</th>
<th>Rigid structure</th>
<th>Light structure</th>
<th>2000mm</th>
<th>1500mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Plasma</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>WaterJet</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

The analysis above shows that the packaging system of the plant species are mainly three:

- movement in three axes are driven out of the work piece (the mass of the machine);
- movement in three axes is done by cutting head;
- hybrid movement - the movement of some axes of the work piece is carried out, but other than cutting head.

Because the modular system is designed for processing of sheet materials with relatively large dimensions and weight in order to realize the desired dynamics is necessary to choose the second strategy – moving head. When it is powered transversal beam that is relatively lightweight, given the weight of the workbench and the work piece and allows reaching high speeds (up to 50 m / min) and high accelerations (9,81 m/s²).

In laser machines still can be realized high dynamic requirements necessary work constructively beam to render the utmost in maintaining high stability. It is necessary to evaluate the use of light metals (aluminum) for the implementation of the beam.

In machines for cutting with plasma or water jet requirements on the maximum speed is lower (20 m / min) and therefore the beam is possible to be designed by conventional steel, which would be economically more effective and technologically feasible easily.

Classification of the beam from this perspective is:

- steel beam;
- light beam.

As mentioned above the body of the modular system, there are two sizes according to the width of the work piece and the beam will be here in two versions:

- 1500 mm;
- 2000 mm.

General classification of the beam is shown in Figure 4, and variability in tabl.2.

**Table 2: Modular variants for the transverse beam**

<table>
<thead>
<tr>
<th>Source</th>
<th>Steel beam</th>
<th>Light beam</th>
<th>2000mm</th>
<th>1500mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Plasma</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>WaterJet</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

The above variations of composition with the best performance for a particular task is opting for "moving beam", it combines the most compact design with a stable behavior and high performance with satisfactory access to the work area and opportunities for joint working with more cutting heads.

![Fig. 3 Machine bad and main structure classification](image)

![Fig. 4 General classification of the transversal beam](image)
**Drive system**

After choosing a particular arrangement is necessary to establish the type of drive along the axes. When selecting a particular drive is necessary to take into account the specifics of the processes as dust and water availability in WATER-JET process temperature processes in plasma and laser cutting, precision in each of the processes and others. Primarily in these machines are found drive with ball/screw, pinion / rack and driven by timing belts. There is another way to use linear drive motor, however, it is considerably more expensive than traditional drives and is used primarily in high-precision machines. The main parameters that must satisfy the drives are given in Table 3.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Laser</th>
<th>Water Jet</th>
<th>Plasma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positioning speed (X, Y), [m/min]</td>
<td>50</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Working speed (X, Y), [m/min]</td>
<td>0.001</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Acceleration, m/s²</td>
<td>9.81</td>
<td>9.81</td>
<td>9.81</td>
</tr>
<tr>
<td>Position accuracy, [mm]</td>
<td>±0.05</td>
<td>±0.1</td>
<td>±0.1</td>
</tr>
<tr>
<td>Position repeatability, [mm]</td>
<td>±0.05</td>
<td>±0.1</td>
<td>±0.1</td>
</tr>
</tbody>
</table>

Each of the above options has advantages in a particular area, choosing a particular option requires careful preuchvane the specific characteristics of each process. It is also important to drive effective and most expensive, but without compromising accuracy or another important parameter. Compare different technologies on the accuracy of processing can be seen that the highest accuracy is obtained by laser cutting. Therefore the laser system to be used more accurately drive, such as ball/screw, while water jet and plasma processes and accuracy of processing is less and there can be used more simple drives, such as timing belt/pignon drive. They provide sufficient accuracy through the use of modern materials and technologies in the production of belts and high stiffness of the belt due to the incorporation of steel or Kevlar reinforcing fibers. In addition, timing belt drives are more sensitive to pollution makes them suitable for this type of machinery. In contrast, the process of laser cutting is more precise and requires actuators with higher precision. When it is appropriate for use in ball screw drive.

**4. Modular structure configuration**

In water jet machines and plasma machines, where a water underside located water collecting bath to avoid excessive complexity of the structure shall be elected only two gauge: 1500 mm x 3000 mm and 2000 mm x 3000 mm.

It is necessary to define the basic options of different types of systems, modular system with different sources of cutting. Below are shown the three main systems working composition with the...
laser, fig.6, plasma, fig.7, and water jet, fig.7, in general viewpoint.

Conclusions

- The modular principle of design and composition in CAD environment of cutting machines is completely differ substantially from traditional approaches to design;
- Conception of modular system design for high-speed cutting of sheet material, enabling efficient implementation in terms of modern production machines for various types of cutting (laser, plasma, water jet) and various properties and dimensions of sheet materials;
- Based on the limited range and functionally predefined structural elements structured as completed modules constructed entire cutting systems, the maximum corresponding to the customer’s specific requirements for short lead times and predictable work behavior;
- Defining the main parameters of the systems, meeting the technical and functional requirements for the best combination of quality and cost of production;
- The modular composition of the system offers optimum value of technology for various types of cutting and processed sheet materials;
- Demonstrated three main systems working compositions with the laser, plasma and water jet cutting technology.

Laser system was prototyped in physical machine and was tested in real working environment, approving modular strategy of cutting system composition as positive.

Acknowledgements

This research study is performed by the support of project DUNK-01/3 of National Science Fund, Ministry of Education, Youth and Science, Bulgaria.

REFERENCES