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TESTING OF FORMED JOINTS ON A DESIGNED PROTOTYPE STATION

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In presented paper perform prototype machine which consist of two independent motion axis equipped with force sensors. Used force sensors provide control of forming connection. Special design of the machine provide to make tensile strength test on it. Prepared nine samples to carried out tests, which revealed the influence between change of jaws displacement during plastic deformation and strength of that joint. Created prototype stand base on two independent drive units allow to make that connection possible. Choosing right parameters leads to generate joints which are more than twice stronger than basic sample reaching more than *920N*.

Key words: formed joints, prototype stand, electric drives, clinching, designing of device and tooling,

1. Introduction

Challenges of todays market force engineers to find solutions that would be economically viable and enviromentaly friendly. That is why automotive industry aims to lowering the weight of the car, which is connected with lowering fuel consumption. That influence friendly on the environment and also gives car better motion parameters [1]. Even in todays electrical cars lowering the weight is highly recomended due to maximazing the range of that vehicle. Figure 1 shows how the weight of cars change over the years [2, 3].

To overcome that issue, designers combine together different materials, to create combination of the best properties [4]. It creates new difficulty, which is joining that materials together. Inseparable joints used plastic deformation is one of the resolution of that problem. They do not exhibit the disadvantage of welding or soldering which are thermal expansion, oxidizing layers around the joint etc. The group of that connection are for example: riveting, clinching or adhesive joints [5]. That kind of connection allows of joining different materials together [6] like steel with aluminium [7], aluminum with titan[8], polymers with aluminium [9] or even magnesium with steel [10].

To ensure that connection is possible, there is need to invent appropiate kind of tools, connected with machine. Inventors create different variations of joint until today. For example Ran *et al.* develop clinching process with rectangle punch, which prevents rotation of parts [11]. Peng *et al.* change pertrusion made thanks

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to clinching and punch it to make that joint flat from both sides. That operation gives them better results both in tensile strenght (more than *75%*) and shear strenght (more than *40%*) of the joint compare to normal clinching method [12].

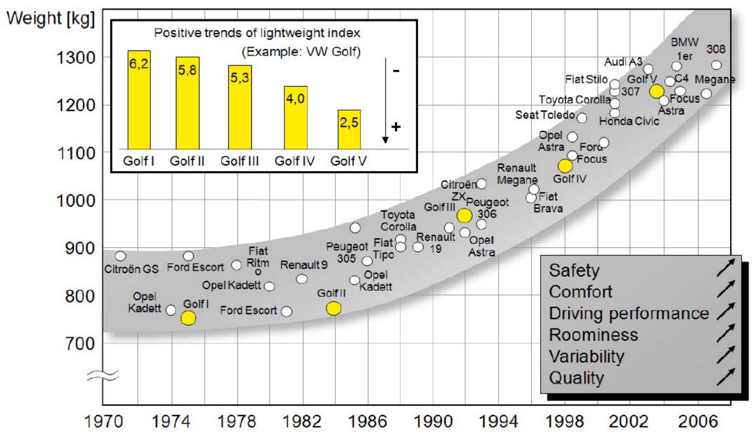

Fig. 1. Trend of in weight of manufacturing cars over the years [2].

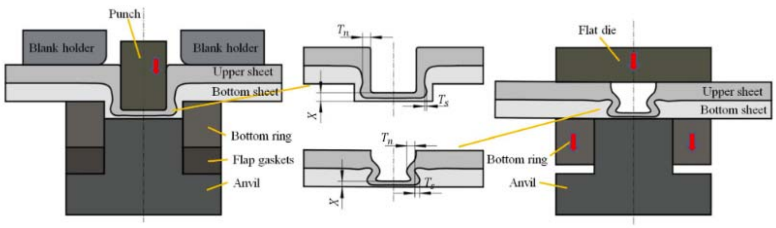

Fig.2. Connection divided on two steps: a) clinching b) reforming protrusion of clinching joint [12].

In sources there is two main tests validate clinching connections. One of them is tensile strength, which shows how the joint behave under tensile load, and other is shear strenght test which put that connection under shear stresses.

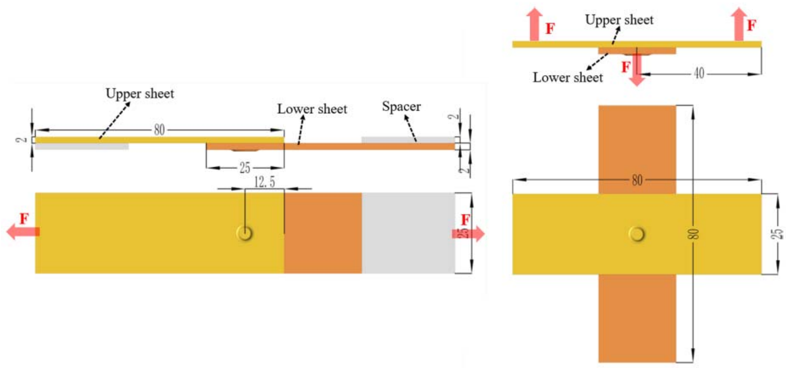

Fig.3. Example of sample under different load directions [13].

Other researches put more emphisize to the original kind of tools or machine. Babalo et.al create electro – hydraulic clinching process, which could work thanks to the electro wave [14]. Vitzhum *et al.* investiate roller clinching process, which is very interesting thanks to the easiness and speed. They check the quality of the clinchpoipnt depend on the roll distance [15].

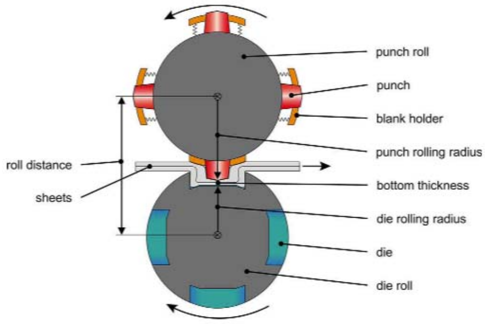

Fig.4. Presentation of rotation clinching [15].

In this study authors check the quality of the connection made and check on the prototype stand.

2. Test stand and equipment

The presented device together with the associated equipment for the joint forming obtained the patent number: 426083 (22) 2018 06 26.

2.1. Test stand

There is many guideline which designed machine must obtain and engineers have to remember during the process. Few of them are mentioned below and had taken into account during design:

- Reach the designed target of using the minimum input to receive the requested strength of product in minimum space of activity
- Stand have to be ergonomic, which means it has to be as much comfortable for operators as it is possible due to variables like function and space.
- Economically reasonable as much as it is possible, usually it is the main factor for manufacturing machines.
- Eco-friendly – that means media consuming or gas emitted should be consider, both during manufacturing and use.
- Fulfilling the task which is assigned to.
- Nowadays appearance of the machine is also taking into account. The stand is very often a advertisement for producer or customer.
- Easy to service, mounting and repair.
- Reliable.

Fulfilling above rules, allow to design a stand, where the main concept base on complex movement of the tool, which can be used also simultaneously in different axis. In this case the main obstacles which have to be solve are:

- Lack of the space, there is need to transmitting great forces in limited space.
- At the end of production this connection has to be tight.
- There is need to measure the forces on the axis which they are working with.
- It should provide quick changeover, to not waste the time during testing.

To reach all of that requirements and avoid changing new tools very often it was essential to measure forces during plastic deformation of the making connection. Figure 5 present sequence of that complex movement. First motion is horizontal to the pipe axis, and the second is going vertical to that axis. This movement is possible thanks to the wedges which push the jaws and multiplicate that forces.

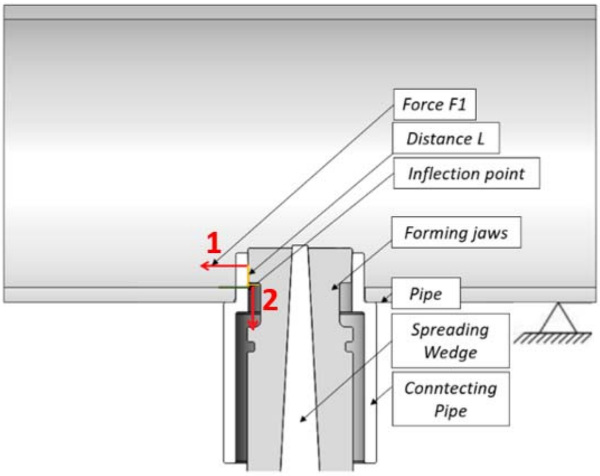

Fig.5. View of the joint and forming tools with the marked point of inflection.

To take full advantage of that prototype machine, it was equipped with two independent drive system. Both of them have to provide force regulations. At the beginning there were performed analysis of that deformation by using different actuators, and finding the forces which are needed. Thanks to that it allow to choose proper motor. They have to be equipped in absolute encoders to verify the position all the time during movement.

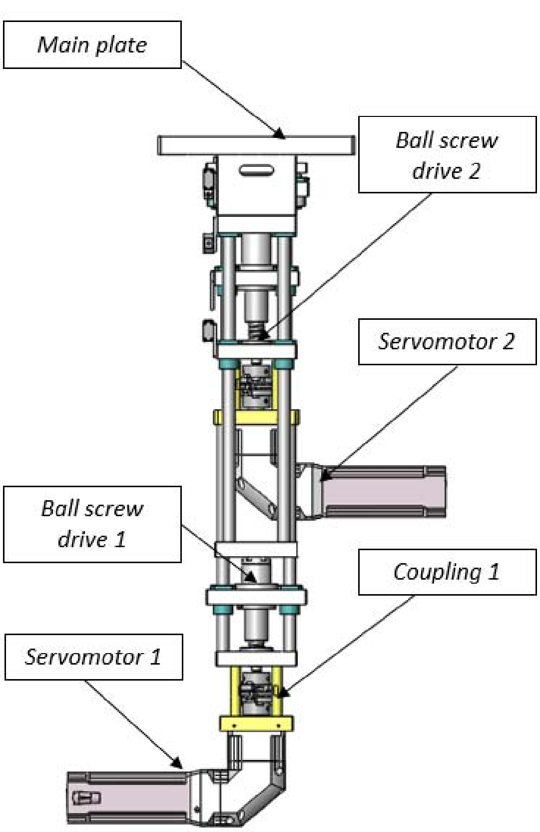

Fig.6. View of patented device with marked main motion components.

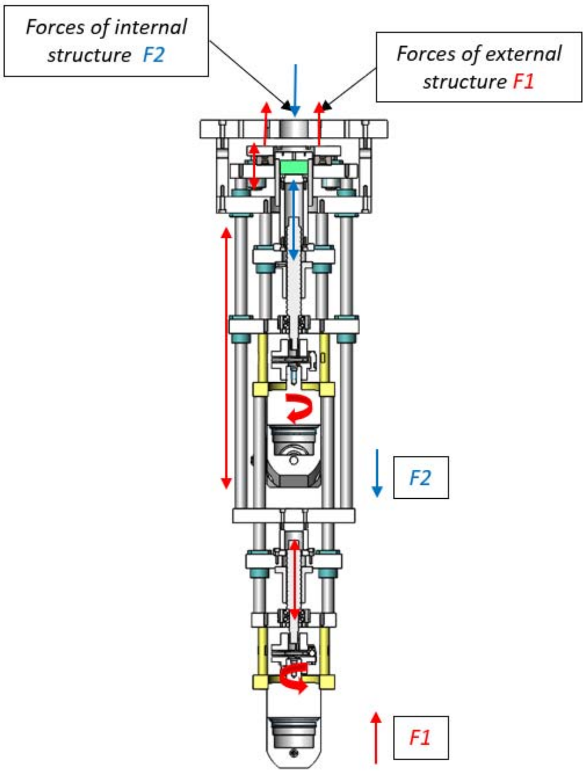

Fig.7. External and internal system forces.

The chain of movement started on engines but then it is transmitted by ball screws which are compiled with planetary gearbox with ratio $1:10$. That solution turns of the need of using wedges which would multiplicate the forces, the other advantage is exclude undesired friction forces. Those require using sensors in shape of ring and button. This two independent drive axis with electronic synchronization allow to eliminate additional gear ratios and errors generated by measurement disfunction. There were performed also FEM analysis which help to understand flow of the material and confirm earlier assumptions and test. That combined with analytical and experimental results, made it possible to determine the needed force on $25\,kN$, for each axes. This described scheme consist of:

- servomotor with a rated torque of $10\,Nm$,
- planetary gear ratio $1:10$,
- ball screw drive with an angular contact bearing built in the *X* system,
- force sensor.

Designed project is based on concept of using plate and shafts alternately. When one drive is need support by using shafts as a spacer between base plates the other one is using the same shafts for sliding on them by using linear bearing. That scheme is presented on Fig.6.

Force distribution is presented on the Fig.7. There could be observed external structure of forces which are responsible for pushing the jaws horizontally. They are marked as red lines. Internal structure of forces is responsible for second movement which is pushing jaws perpendicularly. They are marked as blue lines. Due to the rotary movement transmitted into linear, both of the forces could be very similar.

This prototype stand use electrical and control system based on EMBEDDED PLC controller with installed Windows on it. Thanks to add different computer accessories handling with that system is smart and default. Controler is connected with all devices given signals and provide communication between them which can be observed on Fig.8. The frequency between input and output signals are operated in no less than every 1ms. Those devices are for example Servo motors with nominal $10\,Nm$ momentum and $2300\,RPM$. They are synchronized with absolute optical encoders which provide very good quality of speed and position. Communication between the equipment is thanks to the EtherCAT protocol.

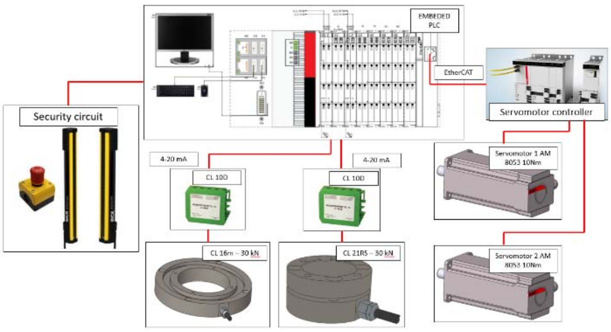

Fig.8. A block layout showing the control and data collectors units, actuators, analog sensors and safety components.

Machine is equipped in two strain gauges CL 16m and CL 21RS which allows reading forces. Both of them have range of $30\,kN$ and resolution less than $0,5\%$. They use CL 10D amplifier to change output values into current of $4-20mA$ which is transmitted to the controller.

Safety on the machine is provided thanks to the SICK safe curtain. It disables dangerous zones on the machine and provide quick entrance after process.

Program for controller is written in TwinCAT environment, which is easy to work with thanks to the modulus structure, which can be connected into one. In this case it allow to combine together two drives in two different axis *X* and *Y*, which represented vectors forces F_1 and F_2. Through to connection both of them into one control unit it allows to reduce delay errors between them.

Thanks to that designed workstation:

- Process is controlled and easy to change.
- Machine allows for quick changeover for other tooling.
- Is safe.
- Is universal for different tools.

2.1. Tooling

Due to the lack of space for plastic deformation and strong forces which are follow that process, special tooling has to be designed. It has to fit in that narrow space in the tube and provide movement at least in one direction. That tooling is presented on Fig.9. which meet those requirements and provide movement in two directions:

- First movement is marked as blue arrows on Fig.9. It is complex motion based on the wedge (9) which is pushing the jaws (5, 6). The jaws are different depends on the directions, fitted to the pipe and connected block (1,2). Embedded in special guide providing that change of movement from vertical to horizontal.
- The second movement is marked as red arrows and they pushed jaws down, providing deformation on the connected block. That is possible because of using external system of pulling which is not dependent on the first move thanks to second drive axis.

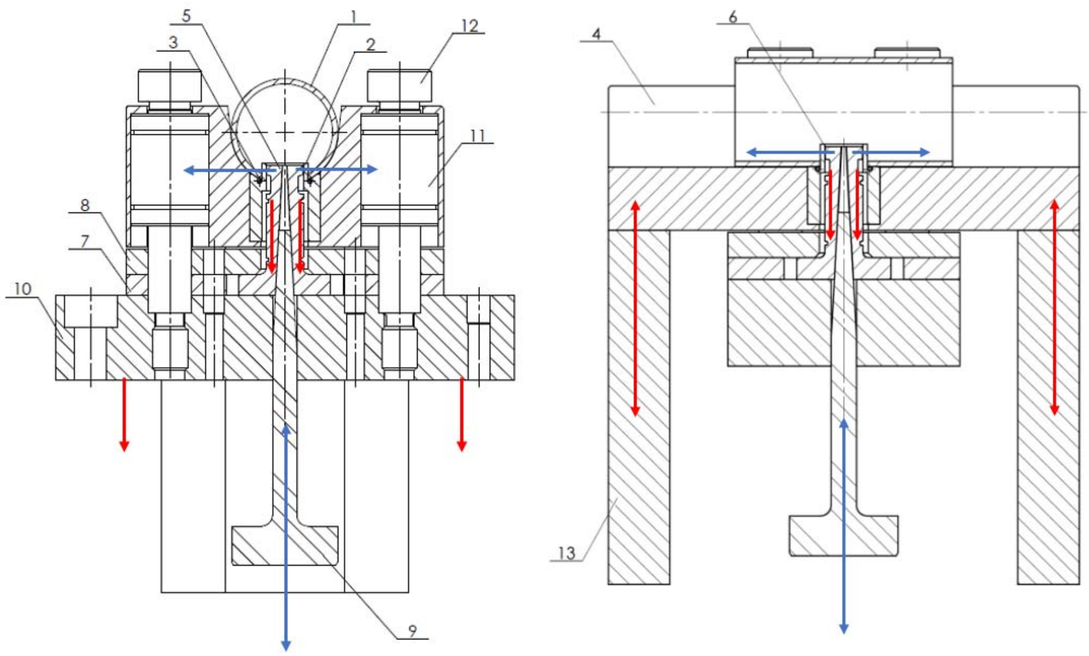

Fig.9. Tooling design.

List of designations in the drawing: 1 – tube, 2 – connecting block, 3 – O-ring seal, 4 – tube die, 5 – low jaws, 6 – high jaws, 7 – jaw guiding plate, 8 – jaw mounting plate, 9 – expanding wedge, 10 – tooling base, 11 – linear ball bearing, 12 – tube die guiding rod, 13 – tube die support.

3. Materials and methods

Project of the tooling and stand allows to create connection by using plastic deformation in two axis. Described sample is consist from pipe and connection block presented on Fig.10. Both of them are made of aluminum 6060, which properties and composition is showed on Table 1 and Table 2 [16,17].

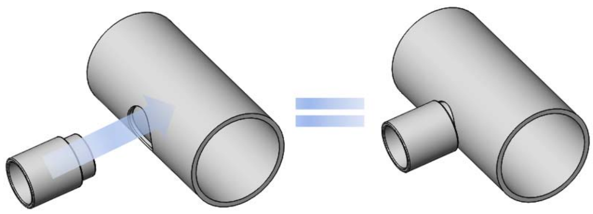

Fig.10. View of pipe and connection block.

Table 1. Chemical composition of aluminum alloy 6060 T4 according to PN-EN 573-3:2019-12 [16].

Si [%]	Fe [%]	Cu [%]	Mn [%]	Mg [%]	Cr [%]
0,30-0,60	0,10-0,30	0,10	0,10	0,35-0,60	0,05
Zn [%]	Ti [%]	Other		Al. [%]	
		Each [%]	Total [%]		
0,15	0,10	0,05	0,15	The rest	

Table 2. Mechanical properties of aluminum alloy 6060 T4 according to PN-EN 755-2:2016-05 [17].

Alloy		6060
Condition of hardening		T4
Tensile strength Rm [MPa]		120
Yield strength Rp0,2 [MPa].		60
Extending	A50mm % min	14
	A % min	160
Brinell hardness HBS		45

This type of aluminum characterize in first place easy stamping which is significant advantage in many brand manufacturing like windows, doors, frames, cooling systems etc.

Methodology of that experiment is based on jaws which deform the connection block thanks to the complex movement of them in two axis. The jaws fitted the contour of the pipe which allow better force distribution and better connection.

4. Methodology of the experiment

The dimensions of tested sample are described on Table 3 and are presented on Fig.11. The connection between pipe and block connection have *14* diameter and are fit on *H8/h7*. There were use *9* samples to prepare reliable outcomes for combine movement.

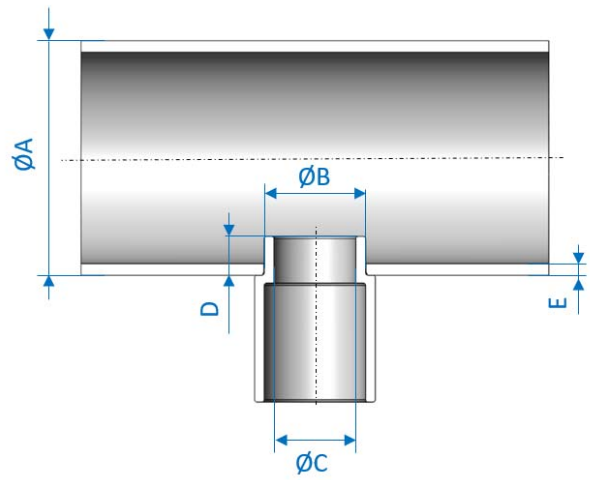

Fig.11. The joint with the characteristic dimensions marked.

Table 3. Geometric dimensions of the joint.

No	Case	ØA [mm]	ØB [mm]	ØC [mm]	D [mm]	E [mm]
1	A	30 h11	13 H8/h7	10,5	5	1,5

Thanks to used two independent motion axis, tested carried out in two different surfaces. One surface is covered by divided jaws into four, which provide motion in four directions. The contour of jaws is fitted to the diameter of pipe, which gives better results and provide from destroying the connection. Movement of the jaws is closely study thanks to different parameters of movement into two axis which are presented in Table 4. The jaws have special tooth, which reduce forces needed to create a joint and provide from rotating the pieces. The height where jaws started deformation different between *5.0 mm* and *5.5 mm* (Fig.13).

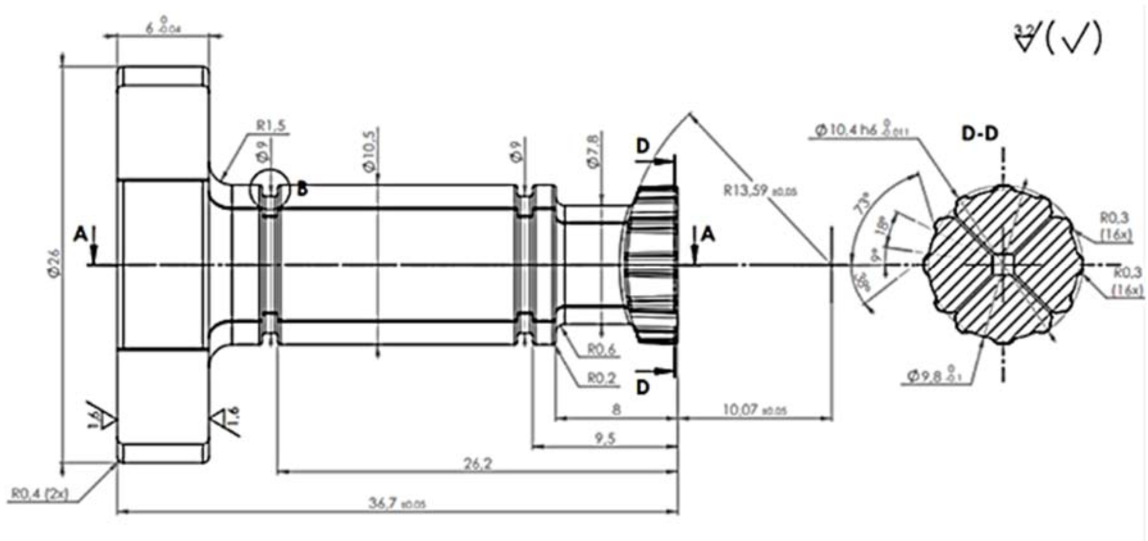

Fig.12. Tool used in the experiment.

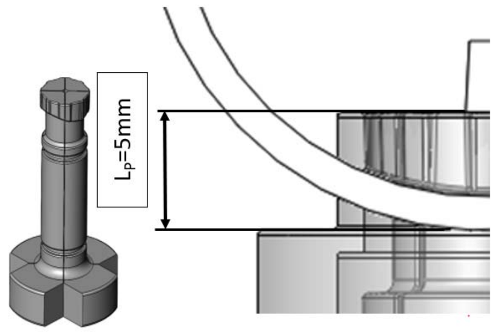

Fig.13. Joint with jaw contact height.

Table 4. Sample cases with assigned process parameters.

Parameter „Lp”	„+05”		„00”
Type of motion	Type of motion		
	2 axis movement	2 axis movement	2 axis movement
Jaws movement value	0,3mm	0,5mm	0,5mm
Vertical movement	0,1mm	0,2mm	0,1mm
Case	1	2	3
Tensile strength test	X	X	X

5. Results and discussion

In conducted study there were two complex motion used to create the connection. One of them is moving horizontally and the second one is moving vertically. Research prepared *9* samples to perform the study. Speed of the first move was $1{,}83\,mm/s$ and the second move was $35\,mm/s$.

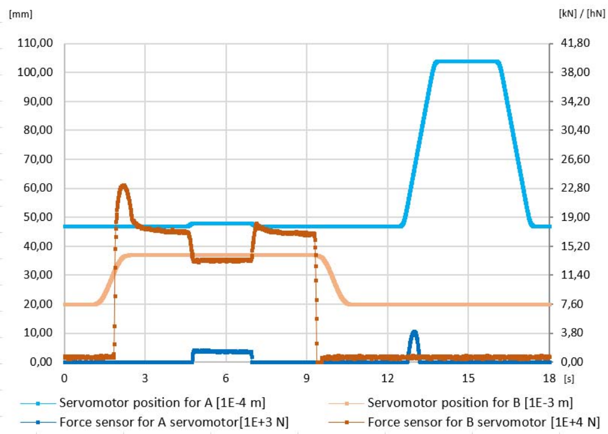

Fig.14. Diagram of displacement and forces registered on the forming tools for four jaw forming process with jaw displacement parameters of $0.3\,mm$ horizontally and $0{,}1$ vertically and force application height of $5.5\,mm$.

First study was carried out with parameters of $5.5\,mm$ for the force application height of the jaws and the first movement of $0.3\,mm$ displacement and second with $0.1\,mm$. For the first movement sensor reach the value of $23.24\,kN$, the value for second movement decrease, which can be related with divided force for sensor A. The strength of that joint withstood maximum force of $408\,N$ (Fig.14).

The second case, was different because of change in first movement on $0.5\,mm$ and second movement on $0.2\,mm$. The value of force sensor have shown $26.5kN$ then the force decrease and is transmitted on the sensor installed on vertical system. It can be noted that the force on second movement is much higher than in the first case. It could be also related of little deformation of the jaws. The strength of that connection is increase to $925\,N$. Which is more 2.26 times better result from the first study (Fig.15).

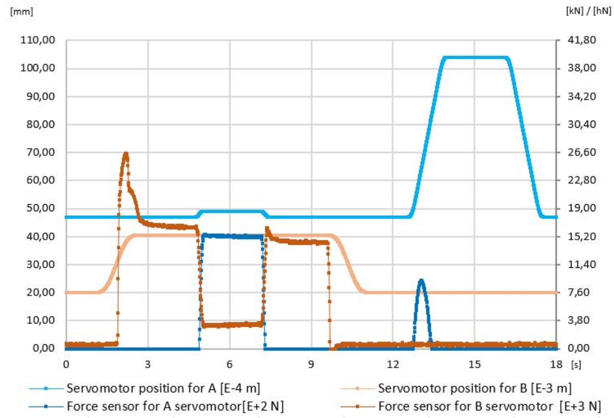

Fig.15. Diagram of displacement and forces registered on the forming tools for four jaw forming process with jaw displacement parameters of $0.5\,mm$ horizontally and $0.1\,mm$ vertically and force application height of $5.5\,mm$.

Last case was manufactured with different parameters of height force application of jaws, described as $5\,mm$ horizontal movement as $0.5\,mm$ and vertical movement of $0.1\,mm$. That gives force of $30.79\,kN$. The curve of force is similar to previous diagrams, but due to change of motion the force is not decrease as much as in second case. The force on external sensor system is almost untouched. It may be connected with the jaws deformation like in the first case. Strength of the connection reach $1014\,N$. Which is the best value of presented cases (Fig.16).

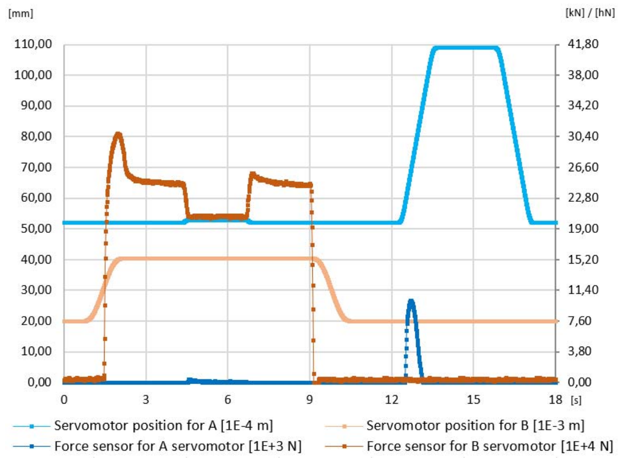

Fig.16. Diagram of displacement and forces recorded on the forming tool for the four jaw forming process with jaw displacement parameters of $0.5\,mm$ horizontally and $0.1\,mm$ vertically force application height of $5.0\,mm$.

6. Conclusions

The conducted research allows to create connection base on complex movement in two surface, which is related to increase in strength of the joint. Thanks to the analyzed cases following conclusions may be presented:

1. System equipped with two independent assemblies of servo motion are able to control the process during the test and provide reliable outcomes.
2. The energy assumption is 14% bigger between case one and two with the same height of force application. During the second test the displacement change 1.6 times for horizontal and 2 times for vertical movement.
3. The strength between first and second case change 2.26 times, which is relations between $925\,N$ and $408\,N$. Which compare to the change of force applied force is a great value.
4. Change in force applied in cases second and third revealed that there is 16% increase. It is related with change of height application force, which shift on $0.5\,mm$.
5. The change of strength between second and third complex moves is only 9.6% better, compare to the energy input that value is not commensurate.

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