A NOVEL TOOL CLAMPING SYSTEM FOR CNC PRESS BRAKES

Evangelos NIKOLIDAKIS[1], George-Christopher VOSNIAKOS[2,*]

[1] Dipl. Mech. Eng., School of Mechanical Engineering, National Technical University of Athens, Athens, Greece
[2] Prof., PhD, School of Mechanical Engineering, National Technical University of Athens, Athens, Greece

Abstract: *Tools of CNC press brakes are attached to the ram of the press by conventional clamping systems ensuring firm support but not easy exchange, because they rely on tightening and loosening of a large number of screws. Some non-conventional proprietary systems are available in the market exploiting pneumatic, hydraulic or mechanical clamping principles and were reviewed to reveal that they provide much quicker tool replacement than conventional systems but they still exhibit some discrepancies. Thus, improved clamping system specifications were designated and a new hydraulic operated clamping system was developed consisting of 18 different types of parts and a hydraulic unit. Detailed design of the system is presented including step-by-step explanation of its function. Analysis of the system pertains to clamping force calculation, to strength calculation of the main parts using finite element analysis, to process plan and cnc program development for the three main components, to design/calculation of the accompanying hydraulic unit and to basic costing. A 'proof-of-concept' prototype was 3D printed. Thus, it was proved that the clamping system satisfies the specifications set and that its production, even in small batches, entails reasonable cost. This is a promising replacement to conventional clamping systems when minimisation of press brake setup time is desirable.*

Key words: *Press brake, bending tools, clamping system, hydraulics, product development.*

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1. INTRODUCTION

High productivity in sheet metal bending is ensured by CNC hydraulic powered press brakes [1], sometimes served by robots [2]. This makes quick change of part batches possible, provided that bending tools can be quickly changed, too. However, most often, conventional tool clamping is employed involving tightening and loosening of a number of screws for each clamping module and a large number of modules. Tools that are horizontally slotted into and out of the conventional clamping modules are interdependent, whilst vertical slotting in and out involves possible risk of accident [3].

Flexibility in sheet metal production on press brakes has been pursued so far by reconfigurable press design [4], control systems [5] mechatronic systems embedded in the press [6] and intelligent bending planning software [7]. However, the tooling and its interface to the press has not received much attention in this respect, despite its paramount significance from both quality and time points of view [8]. Mixed model production is not possible with conventional tool clamping systems, since they render setup time of the press relatively long. Thus, clamping systems with minimal operation time are required. Some companies have introduced such systems, but their use is not widespread. As an alternative, modular tools with integrated tool clamping have been introduced as a concept and R&D prototypes have been built [9].

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* Corresponding author: Heroon Polytehneiou 9, 15780 Athens Greece
Tel.: +302107721457
Fax: +302107724273
E-mail addresses: *mc11059@central.ntua.gr* (E. Nikolidakis),
vosniak@central.ntua.gr (G.-C. Vosniakos)

In this work, a hydraulic tool clamping system supporting the 'Single Minute Exchange Die' principle, possessing simplicity of operation, ease of production and reasonable cost is advocated and a pertinent prototype has been developed. Its design is presented in Section 3, preceded by a short presentation of existing tools and competitor non-conventional tool clamping systems in Section 2. Section 4 gives an outline of analyses performed to ensure strength adequacy and manufacturability of the main parts of the system. Section 5 presents the required hydraulic system, whilst Section 6 proceeds with 3D printed prototype demonstration and a rough cost calculation. Concluding remarks are summarised in Section 7.

2. PRESS BRAKE TOOLS AND CLAMPING

2.1 Tools

Upper tools or punches are primarily classified according to the dihedral angle of the bending edge. Common angles are: 30°, 45° (for so-called sharp punches), 60°, 75° (for so-called free bending punches), 88°, 90° (for closed bending). Their shape depends on the application. The height of the tool is the distance between the bending edge and the support edge on the ram of the press. Upper tools are also classified according to the way that they are supported on the ram. The most recent development is the new standard [3], but the American standard is the oldest, whilst the European standard is without doubt the most widely used. In the case of tools following the American standard, the supporting stem is symmetrically located and the bending force is transferred along the vertical axis.
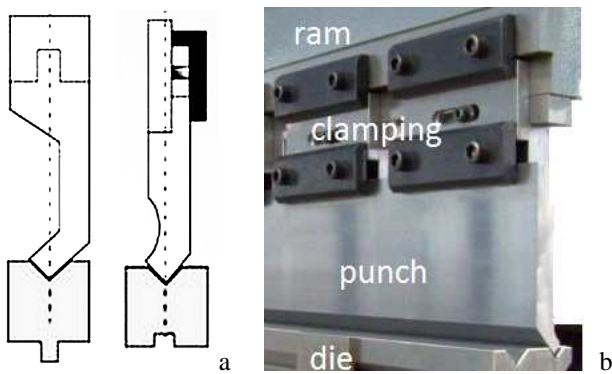
Fig. 1. Bending tools: *a* − American (left) and European (right);
b − conventional clamping system modules.

In the case of tools following the European standard the supporting stem is displaced and is not load-bearing, see Fig. 1,*a*. Thus, the shape of European tools can be more intricate and can accommodate a wider variety of bending forms. However, their clamping system is, by default, more expensive. Standard tool height values for European tools are: 65 mm, 67 mm, 70 mm, 90 mm, 95 mm, 104 mm, and 105 mm. Tools of the 'new standard' have emerged relatively recently as an attempt to combine American and European type advantages and reconcile their disadvantages, focusing on speedy replacement in the vertical direction and hydraulic clamping. However, they are costly, they require special clamping systems and they are still not well-established.

Lower tools (dies) are typically of V-type and they are distinguished by number of V-groves and height.

2.2 Clamping systems

Conventional clamping systems are mechanical, relying on tightening and loosening of screws for clamping and unclamping respectively, see Fig. 1,*b*, whilst the tool itself is typically slotted in/out of the clamp in the horizontal sense. As screws may be at a distance of 100 mm from each other and clamping modules may extend over a length of several meters, it is immediately obvious that the principle of Single Minute Exchange Die cannot be maintained in this case.

There are already some non-conventional clamping systems in the market. A typical 'new standard' tool clamping system can be used with suitable adaptors with any press brake, it enables both horizontal and vertical loading and unloading of tools, it bears loads up to 250−300 t/m and it is made of high tensile steel with yield strength 700−1000 MPa [3]. Clamping is hydraulic, in one typical instance applying pressure of 50 bar on triangular shaped wedges to centre and, at the same time, clamp the tool. It can deal with tools weighing up to 100−300 kg/m. There are also dual mode clamping systems, i.e. mechanical / pneumatic and mechanical / hydraulic, for European tools with vertical loading/unloading, clamping being achieved by tightening/loosening an allen screw or, alternatively, by operating suitable valves. Further interesting hydraulic clamping designs for American tools include wireless clamping/unclamping, low profile to save bending path length and self-contained hydraulic units operating at 35−193 bar and a flow of 7.21−1.42 l/min.
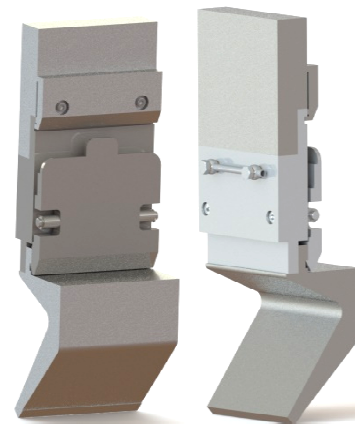

Fig. 2. Clamping module designed with bending tool attached.

2.3 Clamping system requirements

The following specifications were set for tool clamping systems to abide by:
- Accuracy in terms of tool position and alignment;
- Simple and speedy tool exchange;
- Compatibility to european or american type presses;
- Compatibility to european or american type tools;
- High reliability for lowering down-time;
- Long life;
- No constrains imposed on bending stroke and angles;
- Vertical or vertical/horizontal loading/unloading;
- Operator safety.

3. DESIGN

The clamping device designed is shown in Fig. 2. The assembly consists of 18 different types of parts, as shown in Table 1 and in Fig. 3.

Table 1

Bill of materials of the clamping device

| id	Name	pcs	Notes
1	Intermediate plate	1	
2	Clamp plate	1	
3	Hinge base	1	Retained by 6
4	Hinge pin	1	Φ10h6
5	Circlip	2	10×1
6	Socket head cap screw	2	M8×35
7	Piston	2	
8	Piston rod	2	
9	Piston return spring	2	k = 5 N/mm L =20 mm, h = 4mm D_o = 15 mm, D_i = 11 mm
10	Piston guide	2	Trelleborg gp4300200
11	Piston rod guide	2	Trelleborg gr4300100
12	Piston seal	2	Trelleborg psk000200
13	Piston cap	2	
14	Double end banjo fitting	2	10 mm
15	Banjo bolt	2	M10×1.5
16	Copper crush washer	4	M10
17	Clamp securing spring	1	k = 3 N/mm L = 25 mm, h = 8mm D_o = 12 mm, D_i = 10 mm
18	Spring guide	1	Socket Set Screw Flat Point M5×8
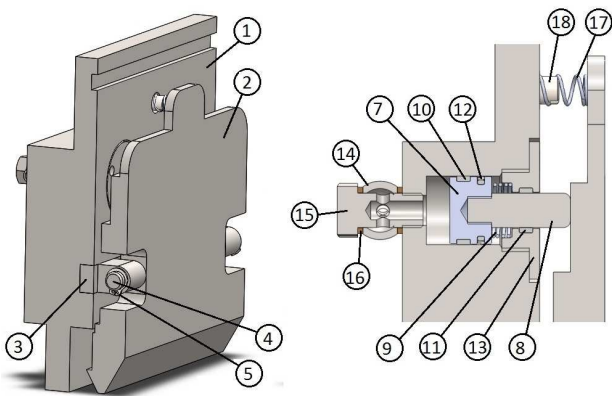
Fig. 3. Numbered parts of clamping module.

The intermediate plate is the interface between the ram of the press brake and the tool, see Fig. 3. The rest of the clamping device parts are assembled on it. The clamp plate is held on the intermediate plate via a hinge that is itself screwed onto the intermediate plate, see Fig. 3. The clamp plate is in effect a lever receiving force by the hydraulic pistons and delivering it to the tool as clamping force, see Figs. 3 and 4. In addition, the clamp plate prevents the tool from dropping off when not clamped by the action of the clamp securing spring. The hydraulic piston is fed with oil through a double end banjo fitting, which is held in place by banjo bolts and sealed through copper crush washers, see Figs. 3 and 4.

The functions of the clamping device are depicted in Fig. 5. In order to release a clamped tool, see Fig. 5,*a*, pressure of the hydraulic circuit is dropped, therefore the two piston rods which contain a pre-tensioned spring recede inside the intermediate plate, see Fig. 5,*b*.
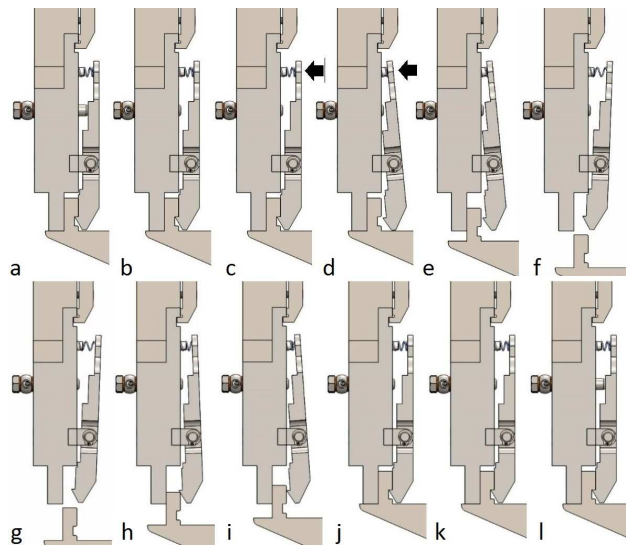

Fig. 5. Clamping device functions: *a…f* − release; *g…l* − restrain.

The clamp remains steady due to the pre-tensioned clamp securing spring. Therefore, the tool is still secured by the hook-shaped end of the clamp plate. By applying a 30N force on the clamp plate's upper end, at the same time holding the tool (see Fig. 5,*c*) the clamp rotates around the hinge (see Fig. 5,*d*) and releases the tool, see Fig. 5,*e*, which slides downwards and is retracted manually (see Fig. 5,*f*) The steps to position a tool are essentially the reverse of those listed previously and are depicted in Figs. 5,*g*...5,*l*.

4. ANALYSIS

4.1 Clamping force

In order to determine the minimum clamping force that the hydraulic circuit should provide, a sample conventional counterpart is studied, such as ROLLERI ST60[TM] [10]. It is assumed that the clamp tensioning bolts are tightened until they reach yield, noting that bolts used are M10 class 8.8, which correspond to a proof load of 33.7 kN. Therefore, for a safety factor of 3.3, due to repeated tightening/loosening cycles, the load applied by each bolt is 11.23 kN. There are two bolts per clamping module, and simple moment equilibrium yields minimum clamping force F_{clamp} =13.6 kN, see Fig. 6.
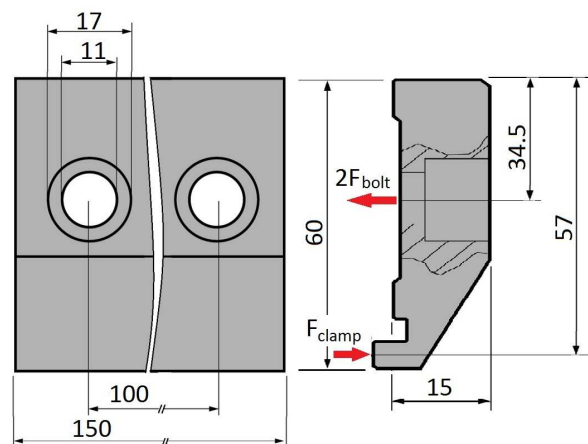

Fig. 4. Parts of clamping module numbered as in Table 1.

Fig. 6. Clamping force analysis on a conventional system.
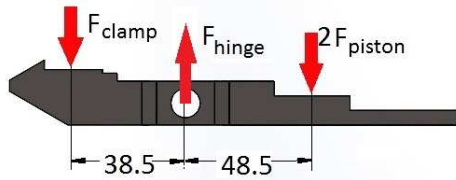
Fig. 7. Clamping force analysis on the designed system.

For a nominal operating pressure of 200 bar on the hydraulic system and a piston diameter of 20 mm the force that each piston exerts is 6.3 kN. Moment equilibrium, see Fig. 7, yields clamping force F_{clamp} = 15.8 kN and the corresponding reaction from the hinge F_{hinge} = 28.4 kN.

4.2 Structural analysis

The most heavily loaded components, i.e. the intermediate plate and the clamp plate were studied using Finite Element Analysis under static loads.

The intermediate plate is loaded by horizontal forces F_{piston} = 6.3kN, F_{clamp} = 15.8 kN and F_{hinge} = 28.4 kN as well as by the vertical bending force F_{bend} = 1000 kN/m, the latter being the nominal maximum force applied on that the conventional system's intermediate plate. These loads were entered in the model created on Solidworks Simulation™, made from AISI-1045 steel. Automatic fine meshing was requested, resulting in 55926 elements of a mean size 4.4 mm. Maximum stress resulted at about 160 MPa, see Fig. 8,*a*, whilst yield stress is 530 MPa. Maximum displacement in the vertical direction at the tool support surface is less than 8 μm, see Fig. 8,*b*, which is easily tolerable, Minimum factor of safety is 3.3, which is clearly a large value.
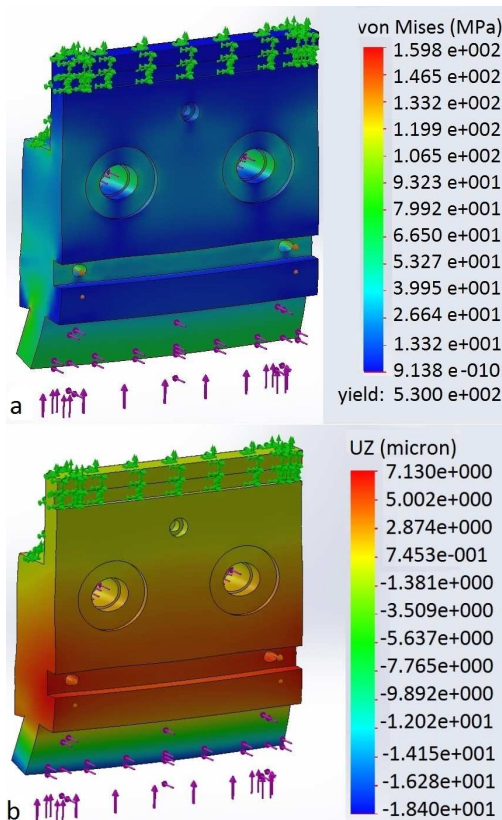

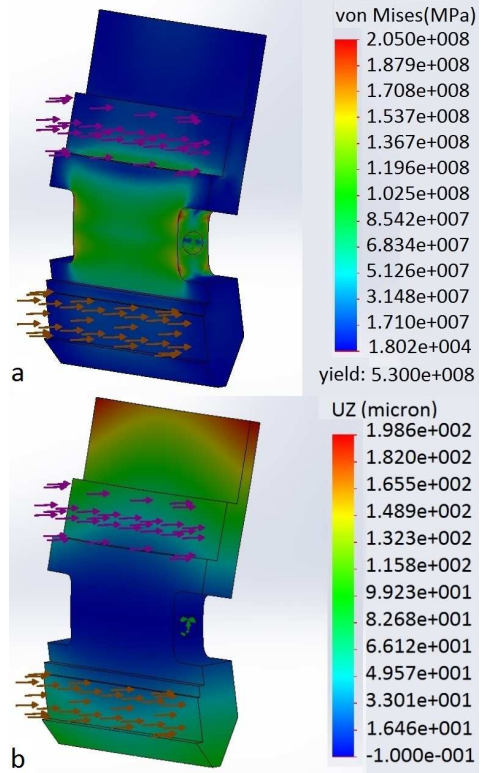**Fig. 8.** Intermediate plate analysis: *a* − stress; *b* − displacement.

Fig. 9. Clamp plate analysis: *a* − stress; *b* − displacement−.

The clamp plate is made of AISI-1045 steel and is loaded as in Fig. 7. Automatic meshing resulted in 55611 elements with mean size 3.13mm. Maximum stress resulted at about 160 MPa, see Fig. 9,*a*, whereas yield stress is 205 MPa. Maximum displacement normal to the clamp plate at the piston interface is about 100 μm, whereas at the tool interface it is 50−70 μm, see Fig. 9,*b*; these are clearly tolerable values. The minimum factor of safety reaches 2.6.

4.3 Manufacturing

The intermediate plate, clamp plate and hinge base are to be created on a CNC machining centre. Solicam™ was employed to produce cnc programs for the respective parts on OKUMA MX45 machining centre respectively. The piston, piston rod and piston cap would be rather bought than created on a turning centre.
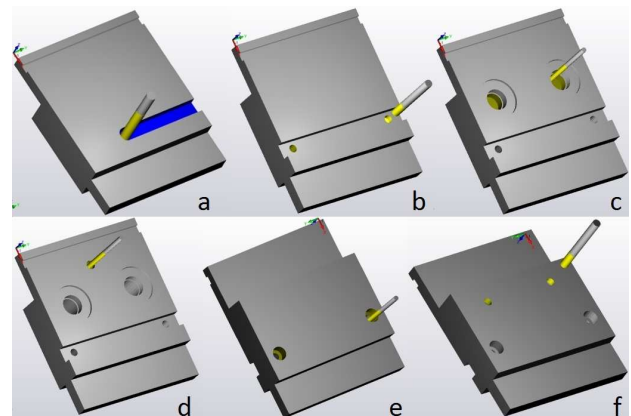

Fig. 10. Intermediate plate CNC machining: *a* – hinge slot; *b* – hinge holes; *c* – piston pockets; *d* – spring guide base; *e* – hinge hole countersinks; *f* – banjo fitting holes.
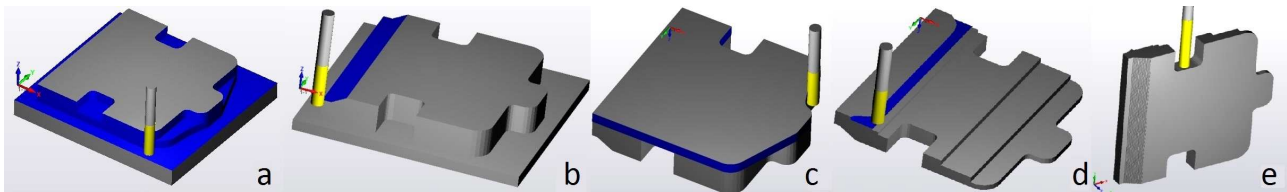
Fig. 11. Clamp plate CNC machining: *a* and *b* – first setup; *c* and *d* – second setup; *e* – third setup.

Indicatively, the intermediate plate is machined from a commercially available part (Rolleri INT150[TM], [10]). The series of operations necessary to machine a slot and several circular pockets and holes are shown in Fig. 10. Two flat end mills (Ø 10 and 5 mm) and a drill (Ø 8 mm) are required in two setups with a total machining time of 13 min. The clamp plate is machined from a parallelepiped with dimensions 180×170×30 mm. A flat end mill (Ø 10 mm) and a drill (Ø 10 mm) are required in three setups with a total machining time of 28 min.

5. HYDRAULIC SYSTEM

Hydraulic power required for system operation is provided by a hydraulic unit, whose design is shown diagrammatically in Fig. 12 and physically in Fig. 13. A stand-alone hydraulic pump is not necessary since it can be safely assumed that the pump of the press brake itself can be relied on. Its operating pressure is usually 200 bar. The main parts of the unit are briefly presented next.

For safety reasons, a relief valve is used operating at 250 bar (e.g. Parker RDH042[TM]). Moreover, the press brake's pump operates intermittently, i.e. to push the ram down at every bending cycle, yet the clamping system needs to remain under pressure continuously. Hence, hydraulic accumulators can be used. For a 4 m long press, 150 mm long clamping modules and two pistons per module with a diameter of 20 mm and a stroke of 10mm, assuming 4 tool exchanges between successive pump operations, the capacity of the accumulators is calculated at 0.7lt. Thus, two accumulators of 0.5 lt capacity each are assigned. The accumulators are loaded by the press brake's circuit but deliver hydraulic power only to the clamping system. Thus, a check valve has to be placed before them (e.g. Parker CVH103P [TM]).
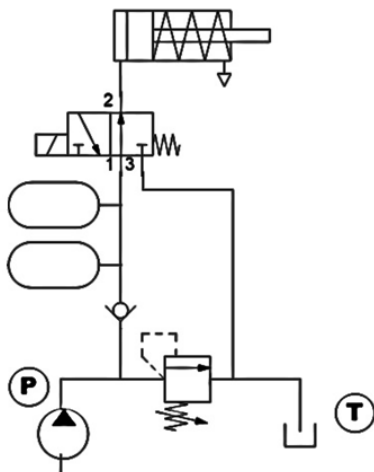
Switching from clamping to unclamping and vice versa is effected by a directional control valve (e.g. Parker Series D1SE[TM]). This has to be 3/2 normally open so that when the unclamping button is not activated pressure is directed to the pistons, whereas when unclamping button is activated pressure is zeroed and the pistons recede inwards due to pre-tensioned springs involved. The hydraulic fluid is collected in the same tank used by the press brake's own circuit. A hydraulic block has been designed to accommodate the components described above, see Fig. 13.

6. RESULTS AND DISCUSSION

Prototypes of the parts to be machined were created on a Cubex[TM] 3D printer using ABS as main material. These were assembled with the rest of the parts to create a full 150 mm long clamping module, see Fig. 14. In addition, a corresponding typical tool module was printed, too. The clamping device was operated manually and was found to collaborate perfectly with the tool both in clamping and in unclamping modes, exhibiting minimum clearance and perfect fitting. Thus, confidence was increased that the metal counterpart will also function as expected under hydraulic clamping force.
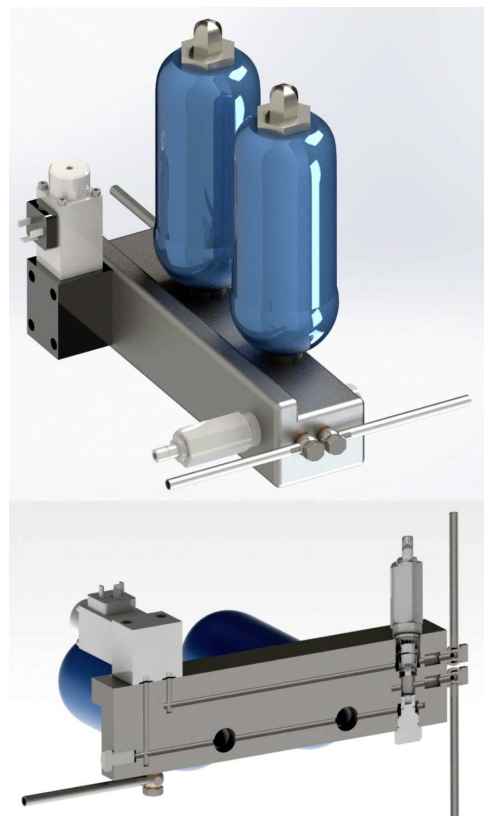

Fig. 13. Hydraulic block designed.
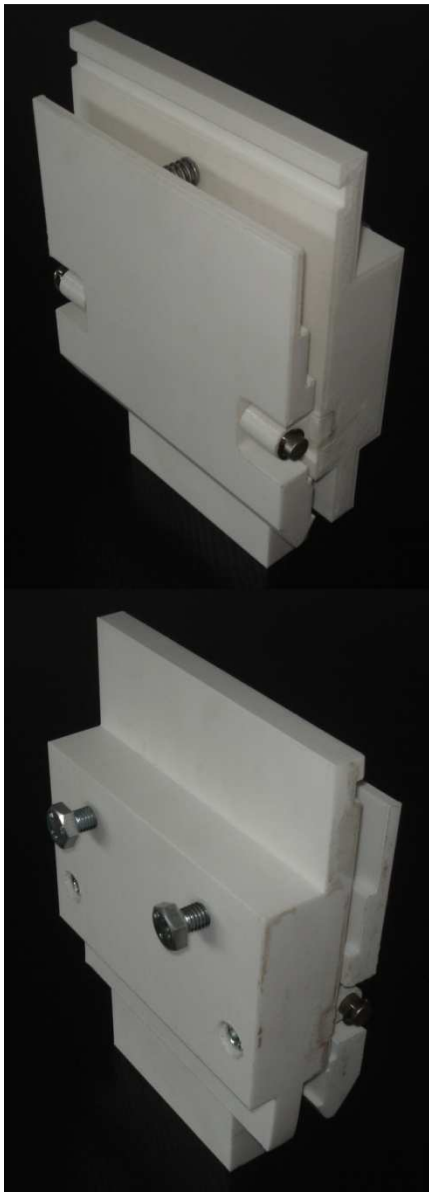

Fig. 12. Hydraulic circuit.

Fig. 14. 3D printed prototype of clamping module.

Based on the design and manufacturing study a preliminary cost calculation was run. The items to be bought cost 176 €, the hydraulic piston assembly costs 2×40 € and the intermediate plate costs 95 €. The raw material for clamper plate and hinge base manufacturing cost about 7 €, and CNC machining for the three main parts (intermediate plate, clamp plate and hinge) is charged at about 70 € (70 min machining and setting up time). Thus, a total cost of 253 € per module is incurred excluding assembly costs and cost of the hydraulic unit. Note that the cost of a similar commercially available system exceeds 400 €.

7. CONCLUDING REMARKS

The clamping device developed compares favourably with the commercially available systems, as follows:

European type tooling and European type presses are supported, which are the most widely used, therefore no new tools need to be purchased upon its adoption.

Fast loading and unloading of tools are possible in a straightforward way in a vertical direction, which makes exchange of existing tools easy. In particular, tool unloading involves turning the button of the hydraulic system to the 'unclamp' position and applying reasonable force to the clamp plate lever for tool release. Tool loading involves slotting-in the tool vertically upwards and turning the hydraulic system button to the 'clamp' position.

The device ensures tool positioning accuracy better than 10 μm, whereas clamping force is higher than in conventional systems.

The clamping module's width is small and its profile is slim, so that it does not affect considerably either the bending stroke or the angular space available for sharp corner bending.

Moreover, the design is relatively simple without special or intricate components, which adds to its high reliability. Its material (AISI1045) can undergo hardening for enhanced durability.

The immediate next step is to manufacture a number of clamping modules and test them in real production, so that corrections can be made where necessary and its performance can be assessed.

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