New solutions for driving the hydraulic fixtures

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***Abstract*—**The linear hydraulic pumps for power-workholding devices proposed in this paper are based on a new concept, these are mechanical actuated by the machine tools. Thus, the pumps have a greater energetic efficiency and are cheaper than other hydraulic power sources like electric or pneumatic power units. This kind of pump is primarily for use in flexible machining centers, in which the power source can not remain connected to the fixture, and for power clamping on portable palletized fixtures. It is a good solution for simple applications with high pressures and relatively low fluid capacities. A several variants of pumps for hydraulic power fixture systems are proposed and compared.

***Keywords*—**clamping device, conceptual design, force amplifying, hydraulic circuit, hydraulic pump, power workholding.

I. INTRODUCTION

Today, hydraulic workholding systems offer many advantages by providing: improved quality due to consistent and repeatable operation, controllable clamping forces (either light or heavy clamping forces can be adjusted), automatic sequencing, fixture compactness, time saved in clamping and unclamping the components. Fixtures often require high pressure (400 bar) for long periods of time (tens of minutes).

The hydraulic workholdings can be powered from the machine tool, from a separate hydraulic pump or from a pressure intensifier. Some manufacturers make high-pressure rotary pumps, rated up to approximately 700 bar, but these pumps are expensive and may heat the fluid. Machine tools with hydraulic drives offer a convenient and inexpensive power source, but operated pressures are low (70 bar). The hydraulic sources like electric or pneumatic power units for workholdings are expensive. Another choice for low-volume/high-pressure circuits are intensifiers. A single-stroke air-oil intensifier, is often called a booster. Typically, air boosters are used to build up pressures for static holding applications. Hydraulic intensifiers are now widely used for fixtures, are small, relative simple, inexpensive and commercially available.

When it is not possible to supply a continuous fluid connection during machining, for example the fixtures mounted on pallets in flexible manufacturing systems, there are several solutions:

- Pallet decouplers, are available for either single-acting or double-acting fixtures, manually or automatically operated.

A pallet decoupler is a unit containing an accumulator, gauge, valves, and quick disconnect [1];

- Enerpac's hydraulic wand cylinder pressurizes pallet [3]. Wand and Booster system pressurizes workholding fixtures mechanically, eliminating the need for quick-acting couplings;
- Hydraulic clamps with internal locking mechanical mechanism [2]. Once activated, the clamps automatically lock and will not release until hydraulic pressure is applied to the release port.

II. ANALYSIS OF THE EXISTING INTENSIFIERS

The simplest intensifier consists of two coaxial cylinders with different diameters and a common piston.

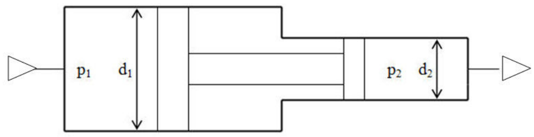

Fig. 1. Fluid booster working principle.

$$\frac{p_2}{p_1} = \left(\frac{d_1}{d_2}\right)^2 \quad (1)$$

The low pressure medium (p_1) is air (~ 6bar) or medium pressure (p_1) oil (~70 bar), usual supplied from the hydraulic system in the machine tool.

Relevant parameters are: diameter ratio (d_1/d_2), the output pressure (p_2) and the volume of high pressure oil supplied per stroke. Based on 1 and 2, this booster has a great drawback: if the output pressure is high and diameter ratio is great, then the oil volume V2 with the high pressure is low (2).

$$\frac{V_2}{V_1} = \left(\frac{d_2}{d_1}\right)^2 \quad (2)$$

Axial-piston style of hydraulic intensifier from figure 2 can supplies high pressure oil per opposite strokes.

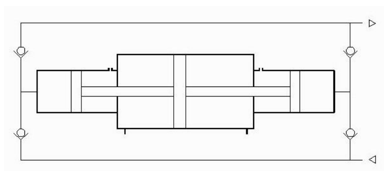

Fig. 2. Symmetrical fluid booster

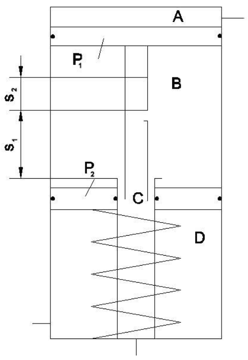

Fig.3. Booster working in two steps

Fig 3 shows an improved air-oil booster which can deliver a high volume of low pressure oil (stroke s_1) and then a low volume of high pressure (stroke s_2) [4].

If the booster is connected with a workholding, the system works in three stages:

1. Workpiece clamping with low force (low pressure and high volume oil): the intensifier starts when compressed air flows in the chamber A, the piston P_1 continues to move fluid until the clamp contacts the workpiece. Farther, the piston P_1 advances until the hole of tubular rod is obturated (stroke s_1). It is possible because the free piston P_2 retreats .

2. Clamping with high force (high pressure and low volume oil): when the hole of the tubular rod is closed, the pressure jumps and the workpiece is strong clamped.

3. Unclamping: The compressed air from chamber A is evacuated and the springs from chamber D, and from clamps push back the oil.

If the elastic deformation of the pipes and hoses is significantly, then stroke s_2 is great, and results a relatively high booster.

For higher volumes of intensified fluid, reciprocating units are available. Reciprocating booster automatically intensifies system pressure giving a higher outlet pressure and will compensate for oil loss on the high pressure side. Because the workholdings need low oil volumes and high pressures reciprocating intensifiers are rarely used.

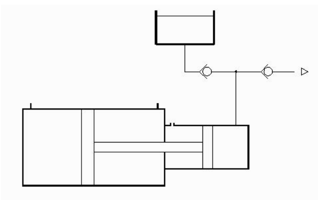

Fig.4. Reciprocating booster working principle

Generally, air-oil intensifiers convert 4-8 bar shop air into 35-2000 bar hydraulic pressure, in small volumes of fluid. Because the hydraulic clamps need maximum 400-700 bar hydraulic pressure, the usual diameter ratio of the air-oil boosters is 10-30.

All of these solutions are commercially available, but are relatively difficult to be applied when it is not possible to supply a continuous air or oil connection during machining. In this case, a reasonable solution for hydraulic workholdings is a intensifier system with self-contained air/hydraulic cylinders, integral tanks and intensifiers that produce low-pressure rapid advance, high-pressure slow work, and low-pressure rapid retract strokes.

III PROBLEM FORMULATION AND SPECIFICATIONS

The new pumps proposed in this paper are mechanical actuated by the machine tools.

Hydraulic pump specifications:

- hydraulic pump for power workholding systems ;
- standalone system (the pump is not connected to other energy sources than the machine tool mechanical force);
- numerical driven by the machining center (MC);
- the force is applied by a rod in the MC tool magazine;
- maximum push force is limited to 2500 N (generally, machining center loading capacity is much more);
- oil volume limited to 200 cm^3 (usually, the oil volume of the hydraulic clamp is 2-20 cm^3);
- closed oil circuit;
- hydraulic system for simple and double acting hydraulic clamps;
- minimum size due to compact standard components;
- cheaper than other hydraulic power sources like electric or pneumatic power units.

IV HYDRAULIC PUMPS CONCEPTS FOR DOUBLE ACTING WORKHOLDING SYSTEMS

Notations: C - hydraulic cylinder; A - accumulator; PS - proximity sensor, magnetic; V - two-way, two-position valve; CV - check valve; PSw - pressure switch; PSe - pressure sensor; PG - pressure gauge.

The variant 1 of the pump for double-acting clamps (fig.5) consists of two standard single-acting cylinders with magnetic piston (C1, C2) and proximity sensors (PS1, PS2): C1- hydraulic cylinder for high volume of low pressure oil, C2 for low volume of high pressure oil; two accumulators: A2- spring-loaded accumulator for low pressure, A1- gas-loaded accumulator for high pressure; V - three two-way, two-position valve; PG - pressure gauge; PSw - pressure switch, and PSe is an electronic pressure sensor. With C3i, i=1- n are symbolized double-acting clamps.

Fig. 5 shows the circuit at rest, and figure 6 the automated working cycle of the system.

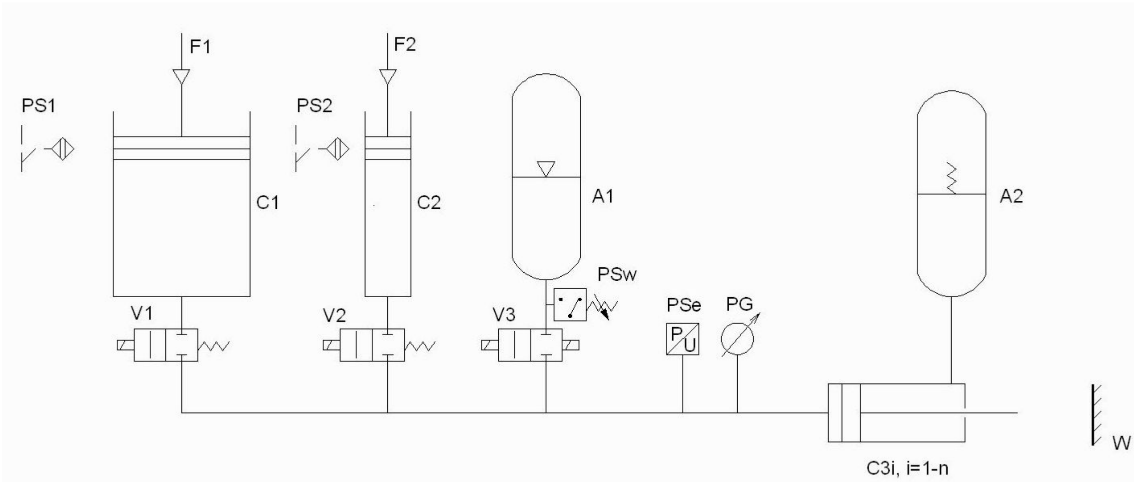

Fig.5. Schematic diagram of the hydraulic pump with two cylinders, for double-acting clamps, variant 1.

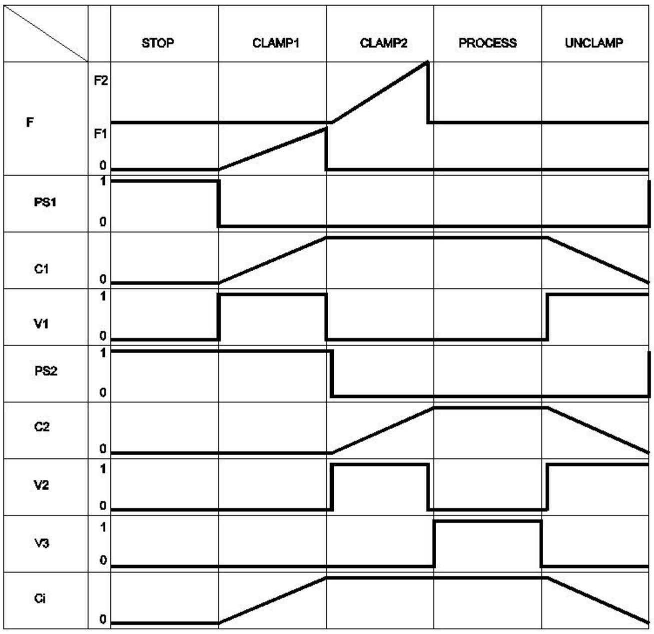

Fig.6. Cycle diagram of the hydraulic pump for double-acting clamps, variant 1.

The system works in four stages:

CLAMP1 with de low clamping force: valve V1 is energized, the force F1 is applied by machining center, the oil flows to clamps, the rods extend rapidly, when all clamps contact the workpiece W, the pressure increases and PSe communicates it to controller. Next, machining center spindle stops, V1 is deenergized, machining center spindle retreats, the force F1 decreases to zero, then spindle goes to cylinder C2.

CLAMP2 with de high clamping force: valve V2 is energized, the force F2 is applied, the pressure jumps and the workpiece is strong clamped, next MC spindle stops. Finally, V2 is deenergized, next V3 is opened and MC spindle retreats.

Workpiece PROCESSING: the high pressure is supplied by the accumulator A2, finally the valve V3 is closed.

UNCLAMPING: energizing the valves V1 and V2 low pressure oil from accumulator A2 pushes all pistons to the start positions.

The pump for double-acting clamps, variant 2 (fig.7) is cheaper than variant 1 (fig.5) because the low pressure accumulator is replaced by a hydraulic cylinder C4.

The system has two closed hydraulic circuits, one for clamp phase and other for return.

The motions performed by MC are more complicated because the spindle have to apply supplementary pull force F3 to unclamp the workpiece and to return the system to initial state. The figure 8 shows the booster cycle diagram.

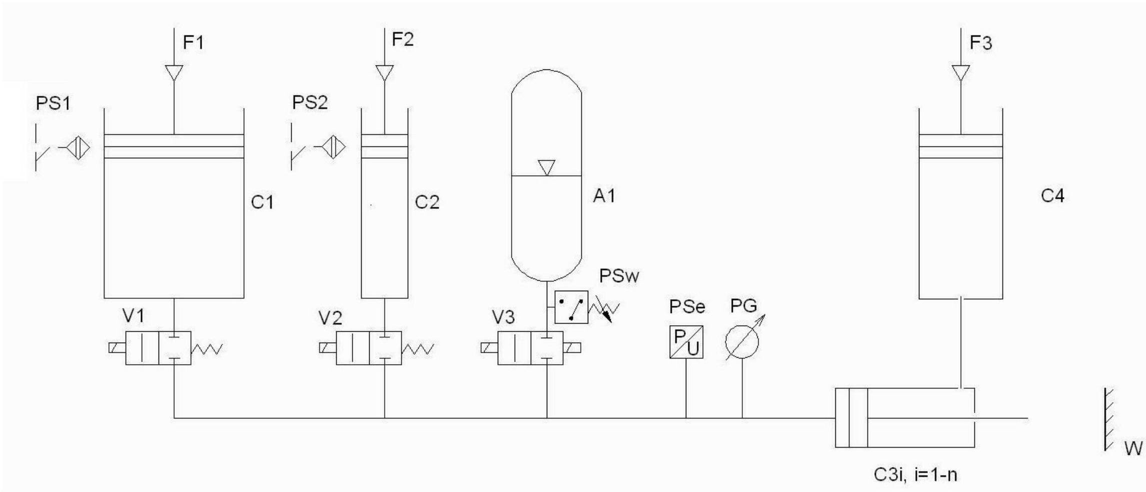

Fig.7. Schematic diagram of the hydraulic pump with two cylinders for double-acting clamps, variant 2.

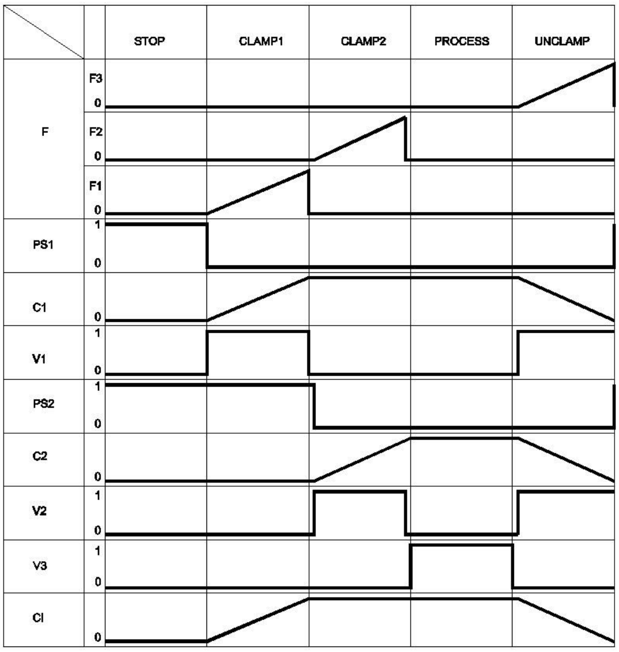

Fig.8. Cycle diagram of the hydraulic pump for double acting clamps, variant 2

The hydraulic pump viability is proved by following example.

Notations:

- d_i, F_i, p_i, s_i, i=1,2 - piston diameter, push force, pressure, stroke of the cylinder i;
- V_{31}, V_{32}, F_3 - clamping, unclamping oil volume; force generated by one clamp;
- V, E, v, L – oil volume contained in cylinders, pipes and hoses; oil Young's module; additional oil volume due hose elastic deformation per 1m linear length when Δp=100 bar; length of the hoses.

Suppose that all clamps are identical and the workpiece deformation is neglected.

To demonstrate the viability of the proposed hydraulic pump, the following numerical data are used: d_2=10 mm (a minimum value of usual tube I.D); s_2= 100 mm; maximum pressure p_2=250 bar; d_1=80 mm; V_{31}=10 cm^3; V_{32}=6 cm^3; E=12.5(p_2+1000) daN/ cm^3; V=200 cm^3; v=1cm^3/m; L=2m.

The most restrictive constraint is the volume conservation during the high pressure clamping:

$$\frac{\pi d_2^2}{4} \cdot m \cdot s_2 = \Delta V_1 + \Delta V_2 \tag{3}$$

where ΔV_1 is the compressed oil volume; ΔV_2 is an additional oil volume generated by the elastic deformation of the hoses and pipes; *m* is the number of repeated strokes.

$$\Delta V_1 = V \cdot \frac{p_2}{E} \tag{4}$$

$$\Delta V_2 = v \cdot L \cdot \frac{p_2}{100} \tag{5}$$

Results: F_2=196 daN (a reasonable push force); m=1.05; F_3=1075 daN (the force generated by one flat clamp).

The variant 3 (fig. 9) has an advantage over variant 1 and 2, it can be used when the multiple stokes are necessary. High pressure cylinder refilling: the valve V3 is deenergized, the spring pushes the piston up, the cylinder C2 is refilled from reservoir. The system has three supplementary components: the reservoir Re, the check valve CV2, and the two-way, two-position valve V2.

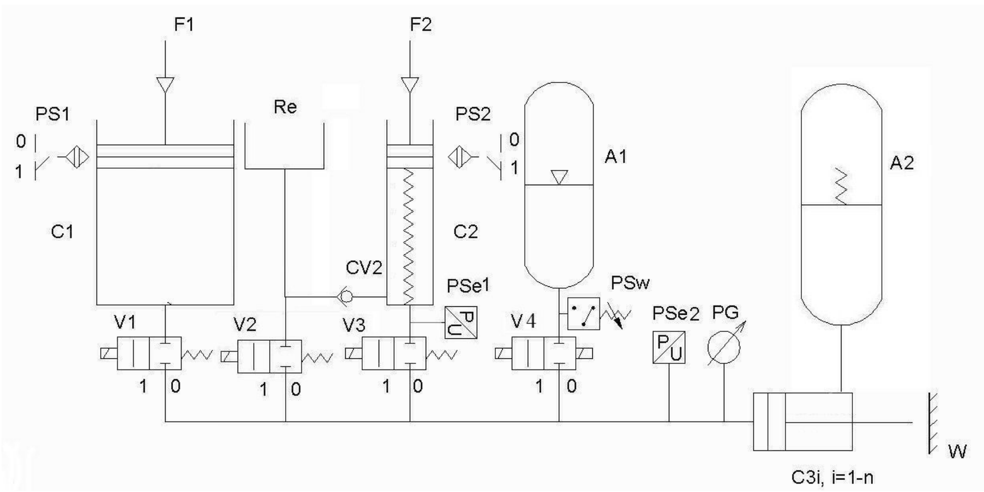

Fig.9. Schematic diagram of the hydraulic pump with two cylinders, multiple strokes, for double-acting clamps, variant 3.

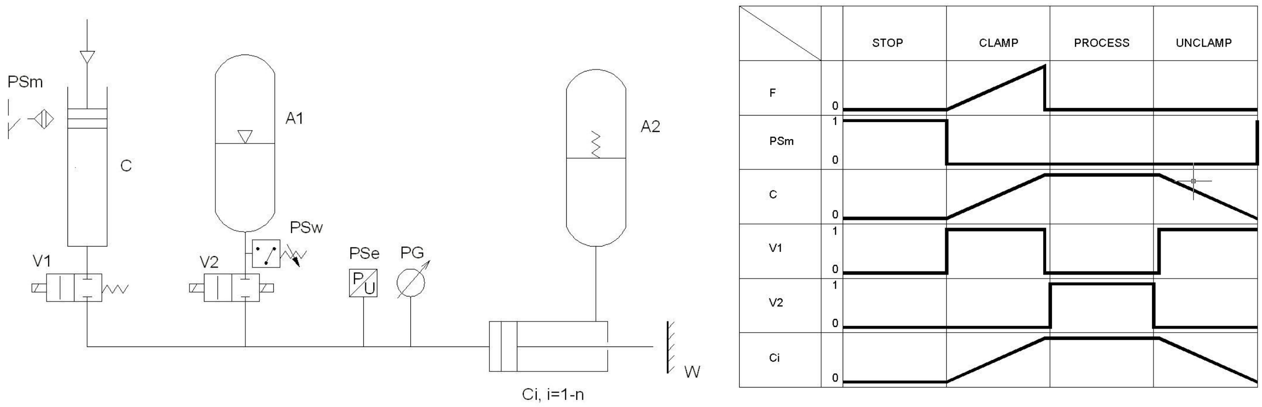

Fig.10. The one stroke hydraulic pump with one cylinder for double-acting clamps, variant 4, cycle diagram.

The pump with one cylinder for double-acting clamps, variant 4 (fig.10) is cheaper than variant 1, 2 and 3 because the hydraulic cylinder with large diameter and accessories were removed. It can be applied if the system works with a low oil volume, with rigid pipes and one stoke is sufficient.

If multiple stokes are necessary the productivity is lower, the motions performed by machining center are more complicated (the push and pull forces must be applied, fig. 11). The variant 5 (fig.11) has a single-acting cylinder, and supplementary components: reservoir Re, a check valve CV and a pressure switch PSe1.

The return stroke of the cylinder C is performed by the machine tool (a pull force is applied).

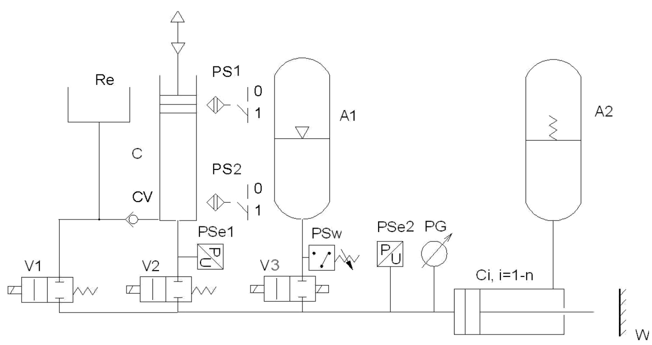

Fig.11. The multiple strokes hydraulic pump with one cylinder for double-acting clamps, variant 5.

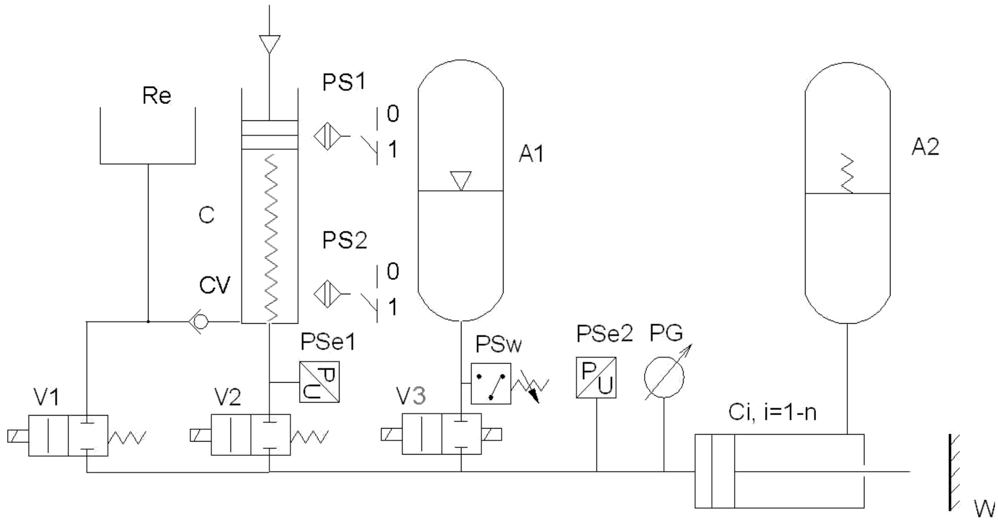

Fig.12. The multiple strokes hydraulic pump with one cylinder, for double-acting clamps, variant 6

The variant 6 (fig.12) uses a spring for return stroke with the advantages enumerated above (see variant 3).

Table I shows the evaluation chart [6] of the six pumps concepts for double-acting clamps, with two or one cylinders.

TABLE I
EVALUATION MATRIX OF THE HYDRAULIC PUMPS FOR DOUBLE-ACTING CLAMPS

Concepts / Criteria	1	2	3	4	5
1	0	0	-	+	0
2	-	-	-	+	-
3	+	+	+	-	0
4	-	-	0	-	0
Σ+	1	1	1	2	1
Σ-	2	2	2	2	0
Σ0	1	1	1	0	3

The criteria are:

1. Structural complexity
2. Number of forces applied by machine tool
3. Output oil volume
4. Multiple stokes

Because the new concepts are compared and other designs do not yet exists, the first datum choice is one of them thinks is the best, variant 6. The following legend is used: + (plus): better than relative to the datum; - (minus): worse than; 0(zero): same as datum. The scores are for guidance only, for a correct evaluation the criteria weights must be considered.

VI HYDRAULIC PUMPS CONCEPTS FOR SINGLE ACTING POWER WORKHOLDING SYSTEMS

The hydraulic pumps for single acting power workholdings are differently built than the previous pumps because the unclamping is performed by springs, therefore the accumulator A2 (see variants 1, 3, 4, 5, 6) and hydraulic cylinder C4 (variant 2) are removed.

Figure 13 shows the schematic diagram of the hydraulic pump with two cylinders for single-acting clamps (variant 7). The system can perform multiple strokes by means of high pressure hydraulic cylinder. It is necessary when the compressed oil volume and the additional oil volume generated by the elastic deformation of the hoses and pipes are significantly.

It works in four stages:

1. CLAMP1 with de low clamping force: valve V1 is energized, the force F1 is applied by MC, the oil flows to clamps, the rods extend rapidly. When all clamps contact the workpiece W, the pressure increases and pressure sensor PSe communicates it to controller. Next, machining center spindle stops, valve V1 is deenergized, machining center spindle retreats, the force F1 decreases to zero, then spindle goes to hydraulic cylinder C2.
2. CLAMP2 with de high clamping force: if one stroke is enough valve V3 is energized, the force F2 is applied, the pressure jumps and the workpiece is strong clamped, next MC spindle stops. Finally, valve V3 is deenergized, next valve V4 is opened and MC spindle retreats. For two or more strokes: when force F2 is applied and the sensors PSe1 and PSe2 indicate the equal pressures, valve V3 is energized and force F2 continues to pull the piston. Refilling: valves V2 and V3 are deenergized, –F2 (pull force) is applied and the oil is supplied from reservoir Re.
3. Workpiece PROCESSING: valve V4 is energized the high pressure is supplied by the accumulator A.
4. UNCLAMPING: valve V4 is closed, next the valves V1 and V3 are energized, the springs push all cylinder pistons to the start positions, finally the valve V2 is opened and the supplementary oil volume due pipes and hoses elasticity flows in reservoir Re.

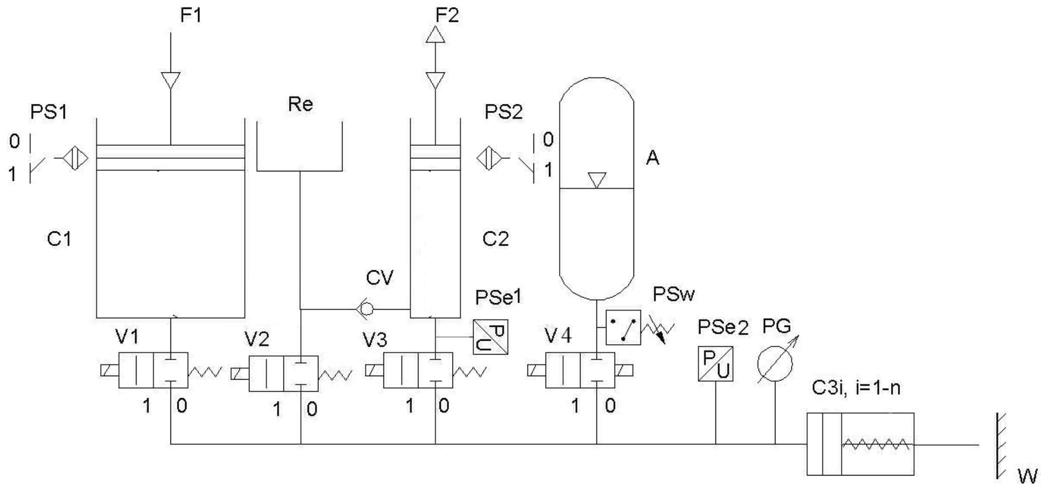

Fig.13. Schematic diagram of the pump with two cylinders for simple-acting clamps, variant 7.

The variant 7 works if the springs are strong enough and the push forces are greater than all friction forces.

A hydraulic pump with two cylinders with spring for simple – acting clamps is shown in figure 15 (variant 8).

Advantages: having an additional spring (see the cylinder C2) the system can be used for any number of clamping devices; the command cycle is more simple (the machining center does not apply the pull force –F2).

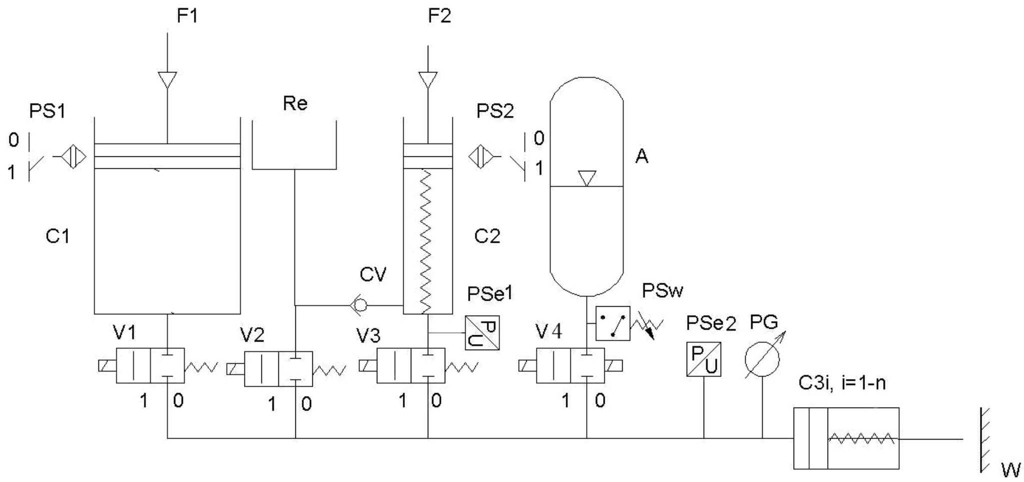

Fig.14. Schematic diagram of the hydraulic pump with two cylinders, spring return, for simple-acting clamps, variant 8.

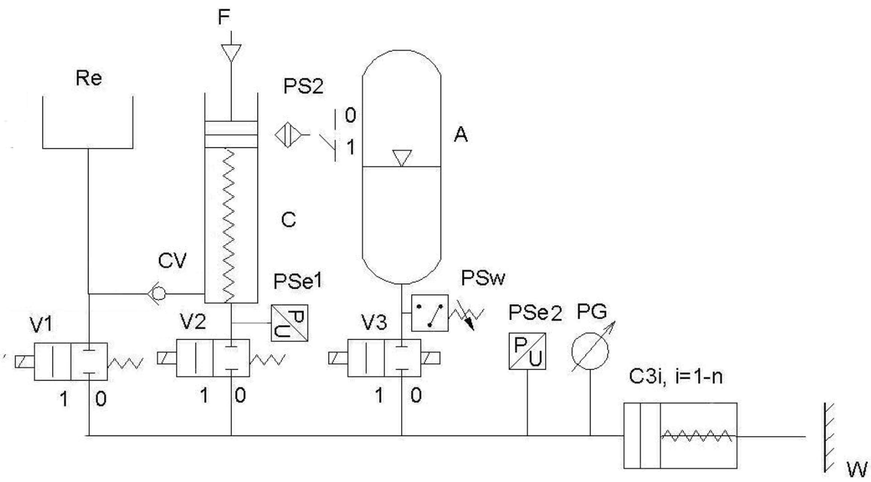

Fig.15. Schematic diagram of the hydraulic intensifier with one cylinder, spring return, for simple-acting clamps, variant 9.

Hydraulic pump with one cylinder, spring return, for simple-acting clamps, variant 9 (fig.13) is derived from variant 8 by removing the hydraulic cylinder C1.

If the elastic deformation of the hoses and pipes are significantly, is possible to repeat the pushing stroke.

Of course, more hydraulic pumps for single-acting clamps can be generated, like the variants for double-acting clamps, but here the most advanced are detailed.

Table II shows the evaluation chart [6] for the three pumps concepts for simple-acting clamps, with two or one cylinders.

TABLE II
EVALUATION MATRIX OF THE HYDRAULIC PUMPS FOR SIMPLE-ACTING CLAMPS

Concepts / Criteria	7	8
1	-	-
2	-	+
3	+	+
4	0	0
Σ+	1	2
Σ-	2	1
Σ0	1	2

Like in table I the same criteria are used: 1. Structural complexity; 2. Number of forces applied by machine tool; 3. Output oil volume; 4. Multiple stokes.

Here the first datum choice is the variant 9. The following legend is used: + (plus): better than relative to the datum; - (minus): worse than; 0 (zero): same as datum.

VII CONCLUSIONS

Using the forces applied by machine tool spindle, standard hydraulic cylinders, simple two-way, two-position valves, gas or spring accumulators, pressure and proximity sensors is possible to built cheap hydraulic pumps for simple or double-acting clamping devices.

In this paper, nine new concepts of hydraulic pumps are detailed, these are a good solution for power workholdings with high pressure (max. 250 bar) and relatively low fluid capacities.

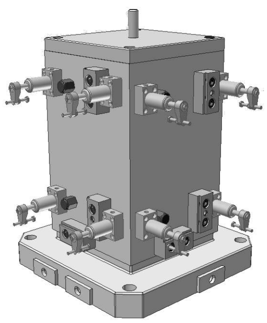

Fig.16. Workholding with a four sided tooling block, including the hydraulic pump, for simple acting clamps.

The present work is focused on conceptual design of the linear hydraulic pumps mechanically actuated by the machine tools, future work will be addressed to detailed design and optimization (fig. 16).

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