A New Concept of Intensifier for Double Acting Hydraulic Power Workholding Systems

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Abstract: Self-contained hydraulic workholding systems offer many advantages, mainly if these are mounted on machining centers. The intensifiers proposed in this paper are based on a new concept, these are mechanically actuated by the machine tool. Thus, the boosters have a greater energetic efficiency and are cheaper than other hydraulic power sources like electric or pneumatic power units. This type of booster is primarily for use in flexible machining centers, in which the power source cannot remain connected to the fixture, and for power clamping on portable palletized fixtures. This system is a good solution for simple applications with relatively low fluid capacities. A several variants of boosters for hydraulic power fixture systems are proposed.

Key-Words: hydraulic power fixture, hydraulic intensifier, conceptual design.

1 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 (250-400 bar) for long periods of time.

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 (boosters). Boosters are now widely used for fixtures, are small, relative simple, inexpensive and commercially available.

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

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

2 Analysis of the existing Boosters

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

Fig.1. Fluid booster working principle.

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

where \( p_1 \), \( p_2 \) are inlet, respectively outlet pressure.
The low pressure medium ($p_1$) is air (~6 bar) or medium pressure ($p_1$) oil (~70 bar), usually supplied from the machining center (MC) hydraulic system.

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

![Fig.2. Two phases hydraulic intensifier.](image)

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Fig 2 shows an improved air-oil booster which can deliver a high volume of low pressure oil (stroke $s_1$) and after that a low volume of high pressure oil (stroke $s_2$) [4]. If the elastic deformation of the hoses is significant, then stroke $s_2$ is long, and results a relatively high booster.

Other category is oscillating booster, it automatically intensifies system pressure giving a higher outlet pressure and will compensate for oil loss on the high pressure side.

All of these solutions are commercially available, but are relatively difficult to be applied in 4 or 5 axes MC because power source does not remain connected to the fixture during the workpiece processing.

3 Problem Formulation and Specifications

The objective is to design boosters based on a new concept: mechanically driven by the machine tool.

Hydraulic intensifier specifications:
- the booster is not connected to other energy sources than the mechanical force intermittently generated by MC;
- numerical driven by the MC;
- usually, the force is supplied by the pusher, a simple rod in the MC tool magazine;
- maximum push force is limited (a reasonable value is 2500 N, generally, MC loading capacity is much more);
- oil volume limited (in this paper 200 cm$^3$, usually the oil volume of the hydraulic clamp is 2-20 cm$^3$);
- closed oil circuit;
- booster for double acting hydraulic clamps;
- minimum size due to compact standard components;
- cheaper than other hydraulic power sources like electric or pneumatic power units.

4 Concepts of Boosters

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.

![Fig.3. Schematic diagram of the hydraulic intensifier for double-acting clamps, variant 1.](image)
The variant 1 of the booster for double-acting clamps (fig.3) consists of two standard single-acting cylinders with magnetic piston (magnetic strip around the circumference of the piston inside the cylinder) and proximity sensors (PS1, PS2): C1 for high volume of low pressure oil, and C2 for low volume of high pressure oil; two accumulators: A2- spring-loaded accumulator for low pressure, and A1- gas-loaded accumulator for high pressure; three two-way, two-position valve (V); a pressure gauge (PG); a pressure switch (PSw), and an electronic pressure sensor (PSe). With C3, i=1- n are symbolized double-acting clamps.

Fig. 3 shows the circuit at rest, and figure 4 the automated working cycle of the hydraulic system.

The system works in four stages (see fig.4):
1. CLAMP1 with de low clamping force: 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 PSe communicate it to controller. Next, MC spindle stops, V1 is deenergized, MC spindle retreats, the force F1 decreases to zero, after that spindle goes to C2.
2. CLAMP2 with de high clamping force: 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. If it’s necessary, step 2 can be resumed.
3. Workpiece PROCESSING: the high pressure is supplied by the A2, finally V3 is closed.
4. UNCLAMPING: energizing V1, V2 oil from A2 pushes all pistons to the start positions.

The booster for double-acting clamps, variant 2 (fig.5) is like the previous hydraulic intensifier (fig.3), but two relevant differences occur:
- the low pressure accumulator is replaced by a cylinder C4;
- the motions performed by MC are more complicated because the MC spindle needs to apply the force F3 to unclamp the workpiece and to return the hydraulic system to initial state.

The figure 6 shows the cycle diagram of this booster.
Fig. 6. Cycle diagram of the booster for double acting clamps, variant 2

5 Viability of the booster, variant 2

Notations:
- \( d_i, F_i, s_i, i=1,2 \) - piston diameter; push force; pressure; stroke of the cylinder \( i \)
- Suppose that all clamps are identical and the workpiece is a rigid one. Fig. 7 [6] shows a double acting flat clamp with different clamping, unclamping oil volumes and a linear dependency clamping force-pressure.

\( V_{31}, V_{32}, F_3 \) - oil volume used in clamping, unclamping phase; 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 \( \Delta p=100 \) bar; length of the hoses.

To demonstrate the viability of the proposed booster, the following input data are used: \( d_1=10 \) mm (a minimum value of usual tube I.D); \( s_1=100 \) mm; \( p_1=250 \) bar; \( d_2=80 \) mm; \( V_{31}=10 \) cm\(^3\); \( V_{32}=6 \) cm\(^3\); \( E=12.5(p_2+1000) \) daN/cm\(^3\); \( V=200 \) cm\(^3\); \( v=1 \) cm\(^3\)/m; \( L=2 \) m.

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

\[
\frac{\pi d_i^2}{4} \cdot m \cdot s_i = \Delta V_1 + \Delta V_2
\]

where \( \Delta V_1 \) is the oil volume contraction due the high pressure; \( \Delta V_2 \) is an additional oil volume generated by the elastic deformation of the hoses and pipes; \( m \) is the number of repeated strokes.

\[
\Delta V_1 = V \cdot \frac{p_2}{E}
\]

\[
\Delta V_2 = v \cdot L \cdot \frac{p_2}{100}
\]

Results: \( F_1=196 \) daN (a reasonable push force);
\( m=1.05 \) (if \( s_1=50 \) mm two strokes are necessary);
\( F_3=1075 \) daN (the force generated by one flat clamp).

6 Conclusion

The intensifiers proposed in this paper are based on a new concept, these are mechanically actuated by the machine tool.

This type of booster is primarily for use in flexible machining centers in which the power source can not remain connected to the fixture.

Using standard components, commercially available, like hydraulic cylinders, valves etc. with exception of special manifold, the proposed boosters are cheaper than other hydraulic power sources like electric or pneumatic power units.

Two concepts for double acting hydraulic clamps are presented, and the viability of these new boosters is proved.

References: