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Technical Solutions of Hydraulic Force Reflection at Master-Slave Manipulators

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ABSTRACT

In this paper the author presents the basic structure of a hyraulic force reflecting master-slave system wich is applicable for industrial robot control. The methods of force reflection is analysed. The new universal master-slave is prescribed from technical and from economic point of view.

1. RESULTS OF PREVIOUS DEVELOPMENTS

The Department of Mechanical Engineering of Banki Donat Polytechnic has developed a hydraulic master-slave with force reflection wich is appropriate for industrial robot control. The first developed master-slave was connected to an ATR-HD-5oo type industrial robot manipulator.

We have reported on this development at the 8th International Symposium on Robotics in Construction.On this master-slave there are two degrees of freedom where direct hydraulic reflection of force perception and two degrees of freedom where an indirect hydraulic reflection of force perception are realized.

2. DIRECT HYDRAULIC FORCE REFLECTION

The main point in this solution is that by the force there is a pressure created in the actuators of the hydraulic system modified

according to the characteristics of the executive mechanism.

Consequently it means that the general force generated at the final point of the robot arm according to the degrees of freedom of the arm-mechanism and through the modification of this transmission is decomposed to the separate executive elements where the balance with the actice force is kept by the force generated by the pressure of the hydraulic-oil power.

In cousequence the appropriate use of this solution with a universal force percepting master-slave can berealized if the generated force is not dependent on configuration. This solution was used with the two degrees of freedom in force reflecting hydraulic master-slave which had been developed by the Department of Mechanical Engeneering of Banki Donat Polytechnic. The perfect "force-copying" assured that with this solution the excutive slave mechanism had two turning degrees of freedom - where the orientation of the final point of the robot arm was not changing anyway - which realized independent movements in a natural way. There were two hydromotor here as actuators.We have generated the pressure difference at the in-and-out points of the hydromotor which were directed to the two sides of the hydraulic cylinder situated on the master slave, generating force perception.

3. INDIRECT HYDRAULIC FORCE REFLECTION

In case of this solution the force at the final point of the robot is measured by either a piezo-electronic force transducer or strain gauges.

After signal formation and transformation this force is directed to a hydraulic pressure reducing valve and with the help of this valve we produce the pressure signalproportional to the percepted force and necessary for the hydraulic cylinder generating force perception. The above mentioned special development carried out by our Department - see Figure 4. - realized to the force perception on a grinding machine with the help of force-measuring cells. On Figure 4.2 the axis of the grinding machine is 1., the bridle which serves to direct the force is 2, and the force-measuring cell is 3.

Therefore the deformation is generated between the bridle and the intermediate part marked 4 which makes a slight movement. In case of this solution we carry out the perception in electronic way independent of the hydraulic system.

4. MASTER-SLAVE WITH FORCE REFLECTION

The master-slave is a four degrees of freedom device where each degree of freedom means a certain movement of the robot arm.

- Turning of the arm of the master-slave by $\pm$ 3o degrees around the vertical axis means the turning of the robot joint around the vertical axis.
- Tilting of the arm of the master-slave by $\pm$ 3o degrees aroundthe horizontal axis means the forward and backward horizontal movements of the robot arm.
- Tilting of the consol of the master-slave around the horizontal axis by $\pm$ 3o degrees means the up-and down vertical movement of the robot arm.
- Tilting of the consol of the master-slave around the vertical axis by $\pm$ 3o degrees means the turning of the robot arm around the vertical axis.

The deviations from the medium position of the master-slave are proportional to the driving speed of the robot arm, the robot manipulator is therefore of speed control.

The deviations from the medium position of the master-slave operate a potentiometer through transmission gear. The modification of the transmission is 1:5, so a $\pm 3o^{o}$ movement of the master-slave results in. $15o^{o}$ movement on the potentiometer.

5. CONCEPTION OF A NEW UNIVERSAL MASTER-SLAVE WITH FORCE REFLECTIONS

The master-slave is of such a construction what makes it possible to transfer to the operator's hand the proportionally reduced external forces generated at the working devices of robots, manipulators or of other equipment.

Combining of the four degrees of freedom of the master-slave may

be optional according to the movement possibilities of the equipment since its operational position is indifferent.

Its basic position can be balanced by springs or by weight.The force reflection is done by hydraulic cylinders. In case of other solutions known from the technical literature the number of degrees of freedom is less. At the application of four degrees of freedom they consist of at least two arms and the cylinders are connected to the turning and joining points of the arms with angle levers. The cylinders and their bars have joint connections so they require flexible hydraulic oil connection which are expensive and increase the errors in force reflection. In case of high pressure only small diameter pipes can be used which make the dinamics of the reflection worse. With the universal force reflecting master-slaves the fixed cylinders can be connected to each degree of freedom by solid pipe-system. All pressure level and all pipe diameter are applicable.

The propotionals of lever arms may be identical or different. The layout makes it possible to have small structural dimensions and compact shaping. It can be used together with both speed and position controlled installations. The number of degrees of freedom can be reduced or in case of more than four degrees of freedom it can be doubled. Without force reflection it can be used for control purposes.The conceptual drawing is shown on Figure 1.

6. THE SOLUTION OF FORCE PERCEPTION

Hereinafter hydraulic connection arrangements are introduced which display at the master-slave, proportional to the cylinders, a back-movement of the arm according to the connections of proportional elements as per Figures 2 and 3 of the reinforced, force-proportional electronic signals coming from the force-measuring cell. The proportional elements may be pressure relief valve - Figure 2 - or pressure reducing ones - Figure 3. The connection realized by two different elements are fed either by a main circuit pump with a pressure reducing device inserted in it or by a separate small pressure pump.

In case of the connection realized with proportional pressure relief valve the fluid stream after the pressure reducer is divided by stream-stabilizing valves according to the required number of force reflection arm directions. These fluid streams are one by one directed to proportional pressure relief valves and through a control valve assuring forceless state to the cylinder. Without main stream the proportional pressure relief valve lets the fluid stream in the tank. There is no pressure increase in the cylinder, therefore there is no force. At the intermediate values of the main stream the scale of the back-moving arm's force is defined by the piston's surface and by the pressure set by the proportional pressure relief valve.

If the main stream is at maximum, the proportional pressure relief valve closes the free circulation of the fluid stream to the tank, so the pressure in the cylinder will be of a value set by the pressure-reducer. The cylinder pushes the robot arm to its basic position by a force according to the pistons surface.

In case of the solutions known from the technical literature the pressure is equal with the main streams pressure therefore the required back-movement force of the arm is accompanied by very small diameter cylinders and pistons tubes which raise problems of statics. The connection of the small size cylinders with high-pressure, long, flexible andof appropriate diameter pipes is very difficult and expensive.

With the developed connection arrangement the pressure levels just a small part of the main stream pressure therefore an appropriate diameter cylinder and pistons tube can be prepared, the stability of which corresponds to the required back-movenemt force of the arm. To the force reflection the appropriate control valve of the movement function should be switched on. (e.g. to the turning control valves 6.3-6.4) If we want to operate the two other movements without force reflection, the control valve 5.1 remains in basic position.

If it is required that the robot arm should be locked in the not required operational directions the control valve 5.1 is switched on and the control valve 6.1.-6.6. before the cylinders of the functions to be closed remain in basic position.

In this case the pressure set by the 3 pressure-reducer is on the

pistons's surface of the 7.1-7.6 cylinders and this prevents the pistons's tubes from removing. The force reflection on the master-slave is produced in a way that the reinforced electronic signal coming from the force measuring cell, proportional to the force opens the 4.1-4.6 three-way proportional pressure-reducers, consequently the pressure, in the 7.1-7.6 cylinders increases, i.e. the back-movement force of the arm increases.

The force reflection, the movements without force and the closed state on the robot arm can be produced in any
variation with the switching on or off of the control valves 5.1-5.4 and 6.1-6.6.

Force reflection an the robot arm is produced in a way that the reinforced electronic signal coming from the force-measuring cell in proportion with the force closes the 1.1-1.6 proportional pressure relief valve, cousequently the pressure in the 7.1-7.6 cylinders increases, ie. the back-movement force of the arm increases.

According to the solution on Figure 3 the shunt-connected 4.1-4.6 three way proportional pressure-reducing valves and the 5.1.control valve assuring the locking of the robot arm without force reflection are fed through 3 pressure reducers from the high pressure main stream.

Through 6.1-6.1 control valves after each 4.1-4.6 three way proportional pressure reducer the 7.1-7.6 cylinders are
connected in series.

In the figured basic position the robot arm against the back-movement springs can easily be moved without force reflection because the fluid spaces of the 7.1-7.6 cylinders are connected to the 11 tanks through the 6.1-6.6 and 5.1. control valves. Low pressure short pipes are applicable. The rise of the proportional elements curves are adjustable, so the rising curve of the back-movement force of the arm can easily be adjusted one by one to each degrees of freedom of the robot arm ensuring a comfortable handling. There is only a slight loss in the system.

The connections can be assembled with elements available commercially and they can be extended according to the required number of force reflections.

The powerless free movement without force reflection of the robot

arm can be realized by switching off a control valve. The blocking of the requested degrees of freedom in basic position of the robot arm can also be realized by switching off the relevant pairs of control valves. If the robot can realize the same manipulations by the separate movement in the same direction of its two separate components and if their force reflection is required, the complicated electronic connection may be substituted by a simple automatic hydraulic connection.

These hydraulic connections make it possible that if the operator does not limit the robot arm's movement and if the blocking is out of operation, the robot will avoid the power impulse due to the external force generated on the tool. This possibility can eventually protect the tool and the robot from damaging.

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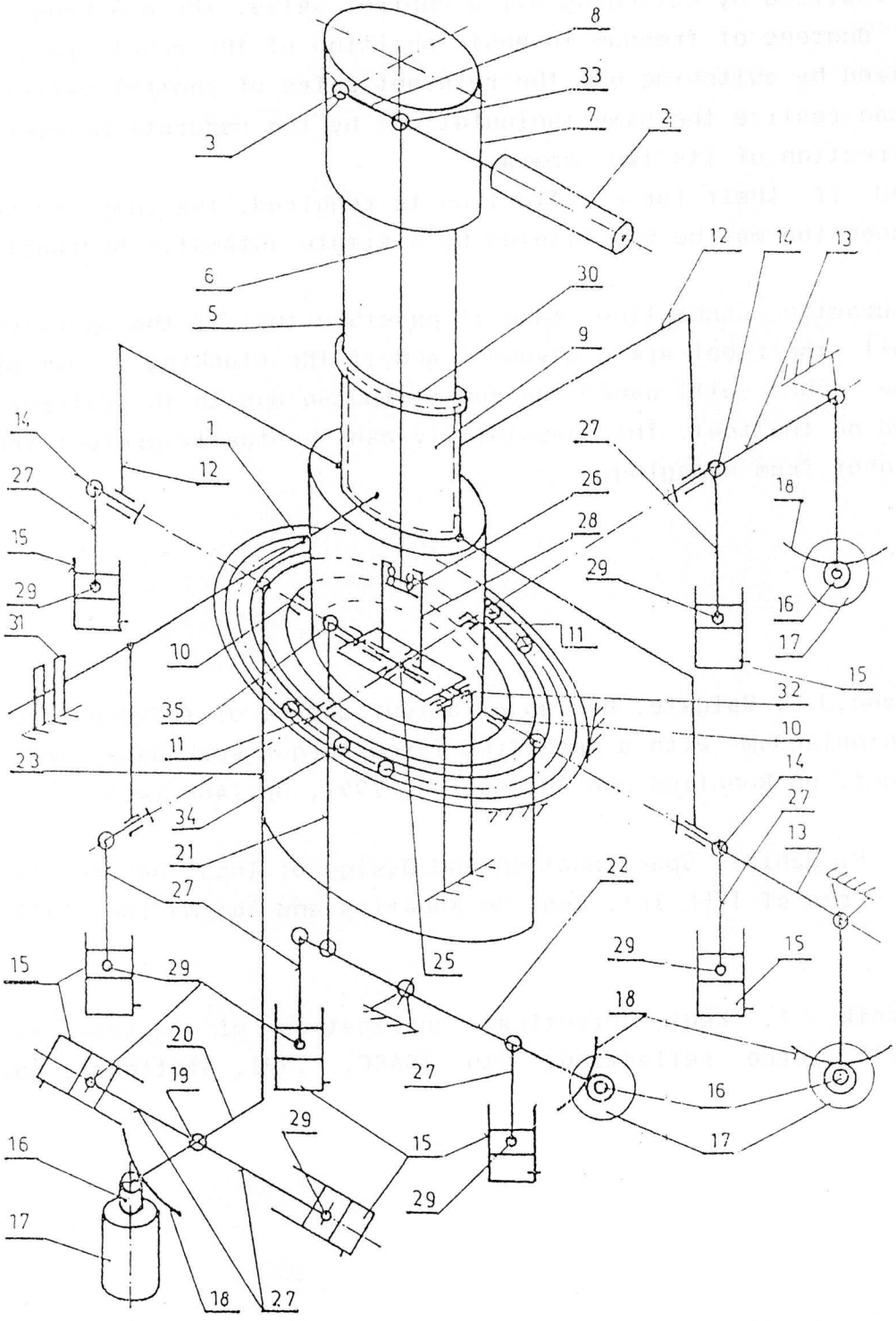

Figure 1 The conceptual drawing of the master - arm

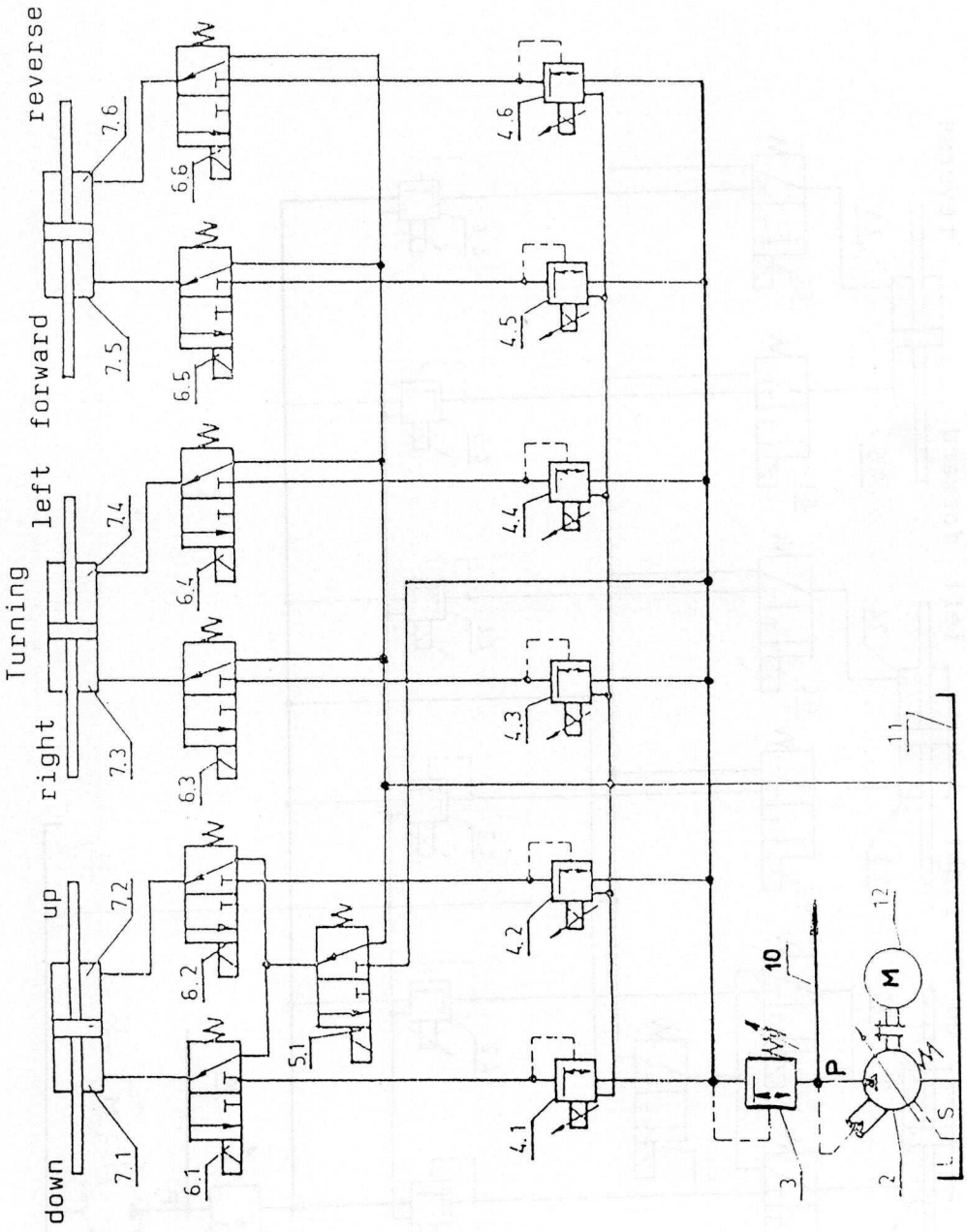

Figure 2 Three Degrees of freedom Proportional Pressure - relief valves

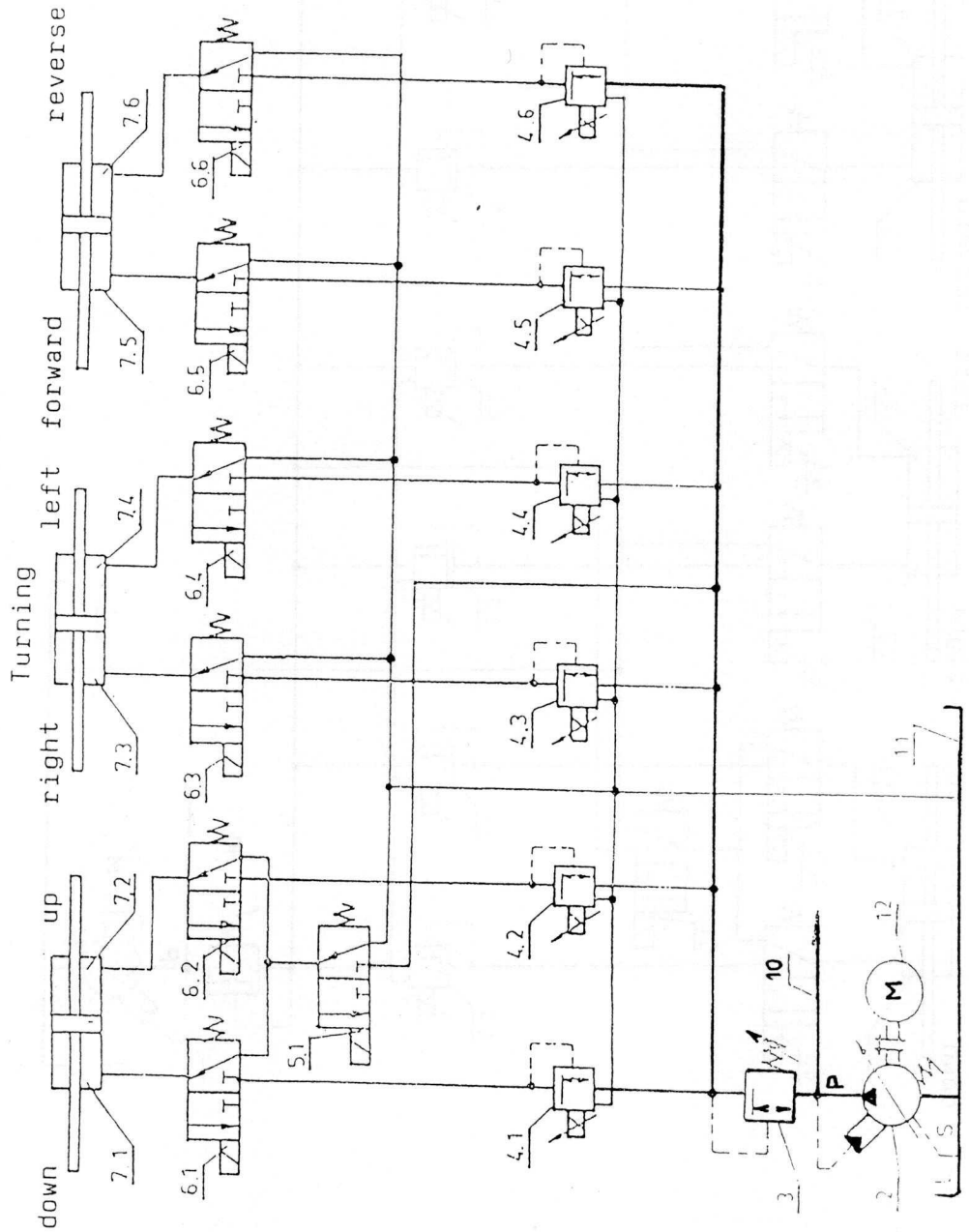

Figure 3 Three Degrees of freedom with Proportional Pressure - Reducers