Hydraulic Model of a Lifting and Handling Manipulator

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**Abstract:** This publication concerns hydraulic robots used in flexible production lines, in fact in hydraulic systems, energy is transmitted and controlled by means of a pressurized fluid circulating in a circuit. which form a new series of applications pick & place (Patents: N° 950799623622 AL 1996088,9622856 AL 19960801, 9620818 AL 19960711, …). Circuit diagrams are an aid facilitating the understanding, study and description of production cells. The new, very simple structure of the hydraulic robot is a novelty in Algeria and has been adapted to the data of a production line made up of seven production lines. In order to avoid any confusion and error during development, production, installation and maintenance and in order to transform this production line into a flexible cell, it appears essential that these diagrams be linked to a standardized representation.

**Keywords:** CAD modification, trajectories, Pick & Place (Signals input-output).

1. INTRODUCTION

Used in industry for decades, the industrial robots currently in service are manipulator-type robots. They are well established in modern manufacturing processes and are used to increase production volume and improve product quality. In the automotive industry, they replace workers in arduous, repetitive or dangerous tasks (painting, welding, etc.). The study relates to the description of a hydraulic model of a pick & place robot for the automation of a system allowing to perform operations of dosing, lifting, distribution, handling, delivery, packaging and packaging for biscuits or cheese... [1 et 2].

State-of-the-art commercial hydraulic manipulators are always justified by controlling each actuator separately. Such systems are relatively energy efficient because they use an offset center pressure compensated proportional control valves combined with hydro-mechanical. In addition, some advanced smart systems are available. It should be noted that a similar system is quite difficult to achieve in high performance critical breaking servo valve systems that require either some valves or counterweight valves for state shutdown. These security features are often a requirement of standards for the certification of commercial products, and are rarely addressed by academic research, with exceptions. [3].

![Fig. 1 Hydraulically actuated robotic serial manipulators: (a) Schilling ORION, (b) Cybernetics’s MAESTRO and (c) HIAB031 for academic research purposes [3].](image1)

![Fig. 2 Hydraulically actuated parallel manipulators: (a) IHA’s six-DOF SGP, (b) Concept of a redundant shoulder [4] and (c) Aminiature three-DOF SGP as a part of an endoscope [5].](image2)
The hydraulic diagram shown is developed to describe the relationship between inlet and oil flow for each chamber and replaced the data respectively corresponds to the joint convention. Disregarding external and internal leaks, the hydraulic pressures at each chamber are defined by the differential equations.

Fig. 3Cable cylinder [19].

The executive part (P.E.) and the desk are illustrated in the heart of this paper. The experimental part of the automation is provided by a Matlab Simulink environment.

Fig. 4The internal loop schematic diagram of the HyQ control frame is a low level torque control joint with an external controller [8].

The production operation after optimization of hydraulic components including return valves, actuators, sensors, pumps, double-acting cylinders, and distributors for the realization of a wide variety of industrial consumer products is characterized by a closed trajectory of a series of movement and stopping with delivery of product evacuation using the gripper and this after an improved choice of all the properties. The Ps and Pr are the supply and return pressures. While Pa and Pb represent the pressure in chambers A and B. Ignoring external and internal leaks, the hydraulic pressures at each chamber are redefined by the differential equations.

2. PROBLEMS

Abbreviations and Acronyms

- CTC: Computer Torque Control
- DOF: degré(s) of freedom
- DHM: Denavit-Hartenberg modified
- DMC: Dynamic Matrix Control
- ETFE: Empirical Transfer Function
- GPC: Generalized Predictive Control
- HAC/LAC: Structure Command
- LQG: Linéaire Quadratique Gaussienne
- MCR: Moindres Carrés Récurrents
- MDD: Inverse Dynamic Model
- MDI: Direct Géométrique Model
- MIMO: Multiple Input Multiple Output
- MPC: Predictive Control Model
- SISO: Single Input Single Output (system)
- TFD: Fourier Discrete Transforme
- PFC: Predictive Functional Control

A. Motion Control

The general issues of trajectory generation and learning by demonstration constitute fields of research in their own right and go beyond the scope of this article. We can be interested and refer for example to [10, 11]. Mechanical flexibilities, beneficial from a safety point of view, can induce unwanted vibrations and limit tracking performance. The synthesis of control laws must take this into account, particularly in the context where only motor sensors are available. A damped rejection of disturbances is sought. The disturbances affecting the system consist mainly of load variations or unintentional non-hazardous contact with the environment (not classified as collision) during the various handling tasks. A zero static error is steady
state should be ensured, in addition to a minimum error in following the path.

Fig. 6(a) Internal compensation loop applied to the ASSIST robot and (b) equivalent representation for the command [19].

The target applications mentioned in this section for a centaur robot required to interact with its surrounding environment or target objects without causing excessive forces. Using pure position/speed control for a limbs centaur type robot is not sufficient for such applications. Interaction with the environment or target objects are best dealt with in the torque/force domain rather than in position [14 and 15]. HyQ (mobile platform for a centaur-type robot) is a fully torque controlled robot [8]. The block diagram of HyQ low level torque control (internal loop) with an external controller is illustrated in the above discussion. The various operations that include the descent, closing and ascent of the execution unit as well as unloading using the hydraulic circuits and the judicious modules produced [12].

B. Overview of the technological study

Hydraulic Motor

In this type of actuator, hydraulic energy supplied by a pressurized fluid is transformed into mechanical energy. This results in rotational movement on the output shaft. The intermediate phases are those of the triggering of the Transband in the different phases and the evacuation to the dosing and packaging stations.

<table>
<thead>
<tr>
<th>Table 1 Hydraulic Motor.</th>
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</thead>
<tbody>
<tr>
<td><strong>Motor with one direction of rotation</strong></td>
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<tr>
<td>Hydraulic Motor</td>
</tr>
<tr>
<td>Variable displacement</td>
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</tbody>
</table>

Hydraulic Robot

The industrial robot (fig. 8) is secured to a base (1), held at its lower part by a body (2), which also serves as a support for the column of the vertical displacement module and for its interior are notched the elements of the hydraulic circuit.

Fig. 7 Command around a nominal trajectory [19].

Motion control must allow precise and robust positioning and path following against modeling uncertainties throughout the workspace. The trajectories considered in the application context of human-robot interaction can in particular be learned by the user for the execution of a task at a sustained speed. [19] The manipulator arm is the positioning system where the forces acting at the joints are produced by hydraulic actuators INAPI Patent Filed. In our article we are particularly interested in the case of hydraulic motors.

Fig. 8 Elevation view and partially in section of a manipulator robot, with its modules and part of the hydraulic circuit [12].
A CAD software can be used to model all hydraulics systems in 3D; from the tank to the actuators, including the distribution network. With a basic version it is possible to model and integrate the hydraulic circuits. However, software vendors develop specific applications to optimize easy integration into a complex machine environment. 4/2 directional valves driven directly by inductive position control solenoids are used in relevant safety applications. The start and end positions can be checked. Position control is available on single and double solenoid valves.

![Fig. 9Differential cylinder in normal assembly.](image)

**Fig. 9Differential cylinder in normal assembly.**

**Role**
The principle of this cylinder is to transform the rectilinear movement of a piston into a rotary movement around an axis.

**Rotation Module**
The rotation module (fig. 11) consists of two cylinders (1) and (2) installed in the body (3) using the fixing elements (4) and (5). The transmission by rack and the toothed wheel (6) and (7) transforms the rectilinear movement of the plungers (double-acting) into a rotational movement of the column. It is a reversible system having the advantages of a simple realization which can withstand large loads. The part (8) serves at the same time for the guide of the rack and for the fixing the cylinder to the body. The protruding part of the cover (9) allows the movement of the piston (10) to be damped by forming a bed of the oil once it is engaged in the hollow made in the piston. The development of the necessary effort is taken into account in the event of contact. The hand can have a rotational movement actuated by the hydraulic circuit and the positioning of the terminal member on the part to be lifted is carried out by a limit switch contact.

![Fig. 11 Two-cylinder rotation module [12].](image)

**Actuators**
Actuators are the driving force of the system; they transform hydraulic energy into mechanical energy. The most common are jacks and motors. Jacks we can classify jacks into three main categories, depending on their use.

**SAC Single-Acting Cylinders**

<table>
<thead>
<tr>
<th>Non-cushioned cylinders.</th>
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<tbody>
<tr>
<td>1. Single rod.</td>
</tr>
<tr>
<td>2. Double rod. transverse.</td>
</tr>
<tr>
<td>Cylinders with cushioning.</td>
</tr>
<tr>
<td>3. Fixed cushioning in back.</td>
</tr>
<tr>
<td>4. Damping at the front and in back.</td>
</tr>
<tr>
<td>5. Adjustable cushioning in back.</td>
</tr>
<tr>
<td>6. Adjustable amortization</td>
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</tbody>
</table>

**DAC Double acting cylinder**

![Table 3DAC](image)
Hydraulic rotary motor model

The hydraulic motor diagrams shown in Fig. 12 consist of a servo valve and a hydraulic motor. A uv control input, chose the direction and amplitude of the oil flow qa and qb in each chamber A and B.

Expression of joint error

Let us analyze the dynamics of joint error as a function of motor error in the proposed control diagram. The joint equation is evaluated as a function of the reference trajectory qd, compared with that actually obtained as a function of q, makes it possible to express the dynamics of the joint error ea = qd – qa as a function of the motor error em.

\[
M(q)\ddot{\theta} + \sum_{i} F_i \dot{\theta} + K(\theta - \theta_d) = 0 \quad (1)
\]

\[
M(q)\dot{\theta} + H(q, \dot{\theta}) + F_v \dot{\theta} + \tau_{fc} + K(q - \theta) = 0 \quad (2)
\]

\[
\Rightarrow M(q)\dddot{\theta} + \sum_{i} \Delta F_i + \Delta H = K \dot{e}_m \quad (3)
\]

3. HYDRODYNAMIC STUDY

The forward dynamics of the manipulator takes torque as an input to generate a desired articulation movement. In order to achieve high performance precision to follow the torque of the desired joint, we must provide the desired reference torque to the robot with the highest possible precision.
Interpretation of results

A simulation program has been finalized which encompasses the various study steps, including the geometric part illustrated by the different position curves of our manipulator robot (Fig. 13). An adequate operating regime of the robot has been indicated, including the kinematic part (Fig. 14) and (Fig. 15). And at the end the dynamic curves (Fig. 16), where we could not determine the verification characteristics of the module to resistance and rigidity as well as the reliability of our robot.

This program allows us to study any industrial robots for different machining stations, the goal of which is to increase the productivity of any flexible machine shop. It is therefore obvious that the studied models are very far from reality, if the speeds increase. On the other hand, inertial, centrifugal and coupling forces appear and on the other hand the games due to friction and elasticity of all origins are no longer neglected.

It is therefore necessary to review the modeling taking into account these dynamic phenomena. The studied model determined the articualr variables as a function of the generalized forces (or / and torques). The calculation of these variables was done by solving the systems of nonlinear differential equations. For the resolution of these systems of equations, the Runge-Kutta method was used. In the case of flexible manipulators, the actual positioning of a manipulator, whether statically or dynamically (pursues trajectories) inevitably deviates from its desired position, and for various reasons. Likewise, a manipulator never positions him in the same place when the same trajectory is repeated several times. Compensation is essential and the study of a deformation model is therefore necessary; similarly, wear is complex set of phenomena that are difficult to interpret, leading to anemission of debris with loss of mass, dimension, shape, and being accompanied by physical and chemical transformations of surfaces. It generally does not vary gradually depending on parameters such as speed, temperature or time. While certain forms of wear are relatively regular, others, on the contrary, experience very sudden jumps, in ratios which can sometimes range from 1 to 100,000 or more, when certain critical values are exceeded.

Comparison

(P1) The left side of the system of equations (1, 2 and 3) can be expressed in the form linear with respect to the physical parameters. This property is fundamental for the identification and adaptive control.

(P2) The inertia matrix M(q) is symmetric, positive definite. M(q) as well as its inverse can be bounded by a function of q for a large class of robots.

(P3) For an appropriate definition of the matrix C(q, q˙) describing the Coriolis terms and centrifuges C(q, q˙), q, the matrix M(q) - 2C(q, q˙) is anti-symmetric.

<table>
<thead>
<tr>
<th>Polynomials</th>
<th>Low displacement (mm)</th>
<th>Low acceleration</th>
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<tbody>
<tr>
<td></td>
<td>0°</td>
<td>4°</td>
</tr>
<tr>
<td></td>
<td>α</td>
<td>3°</td>
</tr>
<tr>
<td></td>
<td>θ</td>
<td>3°</td>
</tr>
</tbody>
</table>

Comparison

(Comparisons of control laws synthesized in [11]).

The correctors implemented are:

- CTC1: proportional-derivative without internal loop, slow adjustment;
- CTC2: proportional-derivative without internal loop, rapid adjustment;
-GPC before robustification, adjustment maxi. the gain (with internal loop);
- GPC after robustification, with modeled KSy and Sy G tr. (with internal loop);
- H 1to 2DOF and anticipation (with internal loop).

Fig. 1 Block diagram of the HAC / LAC command structure [19].
4. CONCLUSION

In conclusion, a large study on hydraulic manipulators was presented. The end effectors combine flexible properties, palletizing, dosage and packaging during practical evolution on the pick & place robot. A state of the art and has been proposed to compare the different methods in the free space movement control branch of hydraulic manipulators. The behavior of the system was analyzed and the basic equations were exposed in terms of mastery of the kinematic couples. The optimized PNC hydraulic controls and HAC (2D) and (3D) in simulation being merged under similar constants, comparable performance is observed, the HAC control being slightly more reliable with fewer errors at the couplings, and the optimized PNC control being slightly more efficient in generalized coordinate configuration. Finally, let us note that it is strongly recommended to make an extension towards more unified and more efficient evaluation methods in the robotics community to highlight the main specifications of the current methods and the achievements in future research contributions. The performance of the production line has been improved here for a given energy criterion, the origin in the case study of empirical simulation, and probably insufficient. A more detailed study of the power, by considering for example a structured description of the dynamic uncertainties, should allow to consolidate this constraint to improve the energy consumption during the change of configuration. The fundamental challenges of hydraulic robotic systems have been identified with the choice of the prediction horizon is not equivalent between the experimental approaches and the real environment, which significantly increases the order and complexity of the energy problem.

References


