Automation and Robotics in Construction X
G.H. Watson, R.L. Tucker and J.K. Walters (Editors)

Evaluation of the position accuracy of the excavator tool

Fiorenzo Malaguti

CEMOTER-CNR, v. CANAL BIANCO 28, 44044 CASSANA (FE), ITALY

Abstract

The automation and robotics for earth moving machines were introduced to reduce labor cost and increase machines performances, the increment of position accuracy of the excavator bucket obtained by laser and/or automatic control systems meets both objects.

Experimental tests and simulations have shown excavating accuracy to be about two centimeters, the excavating accuracy depends on position accuracy of excavator boom prevalently, also a simulation of the boom dynamic system has shown it, in fact, during the precision excavation the arm is near the vertical position.

The excavator, or the basic machine, is used also as loader, forklift, pipe-layer, drill and more, therefore we consider right to value the position accuracy of all excavator linkages and complete equipment, and the design problems of the control system.

The accuracy evaluation of the complete arm is made by simulation, the evaluated system includes the dynamics of the linkages, hydraulic and power system (hydraulic cylinders, valves, pumps, engine) and the operator.

An important task is made by the operator , he is at the same time the feedback and controller of the machine, the use of the human model in the simulation doesn't prejudice the generality of the problem, because the excavator should became a telerobot probably, while it is less probable that it could become a complete autonomous robot.

The simulation is made using the dimensions and measure values of a microexcavator used as scale model.

1. Introduction

Introduction of the new laser systems in digging operations has allowed the operator to obtain a good performance in precision digging, and to reduce labour cost. These systems, making the necessary external reference, are the main sensors to automate the excavator so as the other earth moving and construction machines.

The present state of automation needs human operator again, he does almost all the controller and supervisor tasks of the machine operations,because he can fit many conditions, therefore it thinks that also in the future he will continue to control the heavy construction robot to fit it at the variable work condition.

In parallel to the research about automation and robotics for construction machines we have thought, therefore, to investigate about operator-machine iteration.

The digging precision depends on the boom position control mainly, but excavator is a multifunction machine by possibility to change the final tool, we analyze the positioning precision of the two main links of excavator, since the precision of the final tools depends on it.

For this analysis we have simulated the dynamics of the boom, arm, hydraulic system and controller model of the operator; putting in evidence the problems cause by the asymmetry of actuator. A dual bang-bang hierarchical model has been used to simulate the operator, this type of model was preferred on the continuous model, because it is more similar real operator behaviour.

The simulation is related to the commercial microexcavator fitted for robotics research.

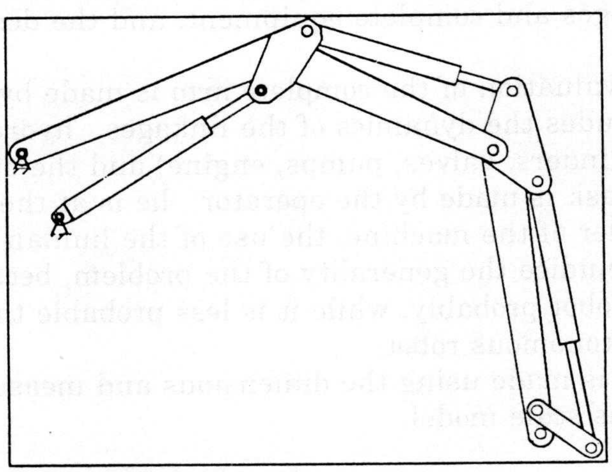

Fig.1 Boom of the microescavator

2. Dynamics of the boom

The motion equations of the boom and arm are given by the following Lagrange equations, the symbols of these equations are explained by fig. 2 .

$$T_1=(m_1h_1^2+m_1l_1^2)\ddot{\theta}_1+m_2l_1h_2\ddot{\theta}_2\cos(\theta sub2)-m_1gh_1\sin(\theta_1)$$
$$-m_2gl_1\sin\theta_1-m_2gh_2\sin(\theta_1+\theta_2)$$

$$T_2=m_2h_2^2\ddot{\theta}_2+m_2l_1h_2\ddot{\theta}_1\cos(\theta_1)+m_2l_1h_2\dot{\theta}_1\dot{\theta}_2^2\sin(\theta_2)$$
$$-m_2gh_2\sin(\theta_1+\theta_2)$$

The torques **T** are given by asymmetrical hydraulic cylinders, of which the forces are given by

$$F=a_1p_1-a_2p_2$$

where **a** and **p** are the area and pressures of two sides of piston.

Inverse kinematics of the link is carried out by simple relationships of a generic triangle made by two links and the distance between the origin and the final point.

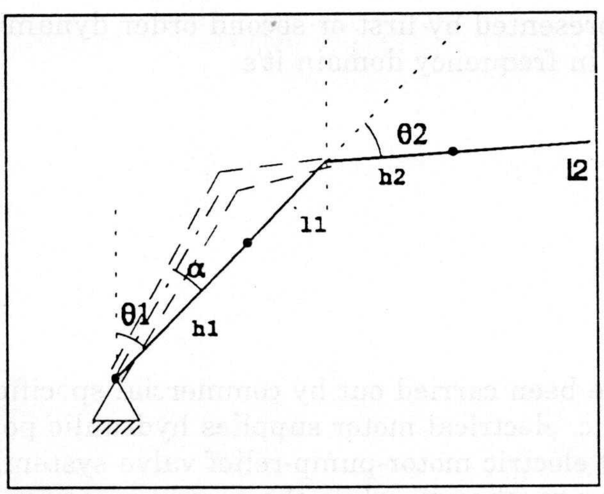

Fig. 2

3. Hydraulic system

The cylinder continuity equations have the usual form

$$\dot{p}=\frac{\beta}{V_0}(Q-av)$$

where β is the bulk modulus, **V** is the volume of a cylinder chamber, **a** is its area and **v** is piston speed.

The flows controlled by every servovalve are given by the following relationships

$$q_1=k_1 i\sqrt{p_s-p_1}$$
$$q_2=k_2 i\sqrt{p_2}$$

where **I** is the servovalve control current.

These relationships can be changed in linear form by

$$q=k_v i+k_p p$$

The servovalve can be represented by first or second order dynamic models, we use the first order model, in frequency domain it's

$$\frac{K}{1+s\tau}$$

while in time domain it's,

$$\tau\dot{q}+q=Ki$$

the valve parameters have been carried out by commercial specification.
A gear pump, driven by a.c. electrical motor supplies hydraulic power, we have neglected the dynamics of electric motor-pump-relief valve system, because electric motor has small r.p.m. change, while the supply pressure is supposed constant; moreover, we suppose that the flow, supplied by power system, is the necessary flow.
In fig. 3 is shown the block diagram of hydraulic system.

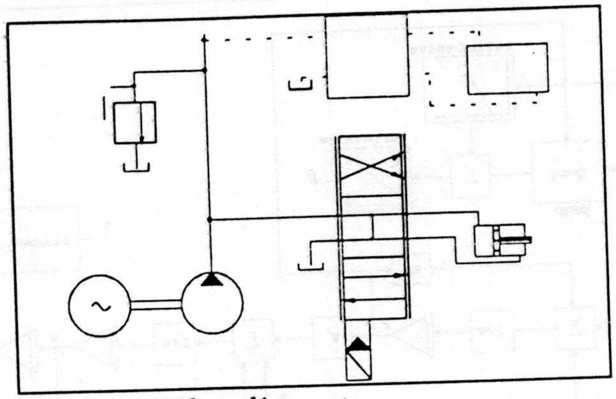

Fig. 3 Hydraulic system

4. Operator model

The operator is a multi imput-multi output controller, but is very difficult to find a MIMO models and they are linear usually, while the human behaviour is high not linear also.

We have used a model developed by Sutton and Towill for a crane, this is dual-mode hierarchical model, where for large control it uses bang-bang mode, while it uses tracking mode for small variations: we have modified tracking mode by a small bang-bang control.

A sample-and-hold and a delay complete the model.

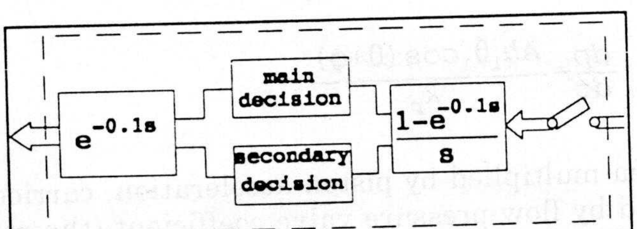

Fig. 4 Operator model

5. Simulation

The simulation has been made using a variable step Runge Kutta method used for linear system usually, but non-stiff methods to integrate differential equations systems are used in machines dynamics widely. As Kuczmarski and C. suggest, we have divided the integration time in three seconds long periods, so that the pressure transients should end, and using a RK method have con-

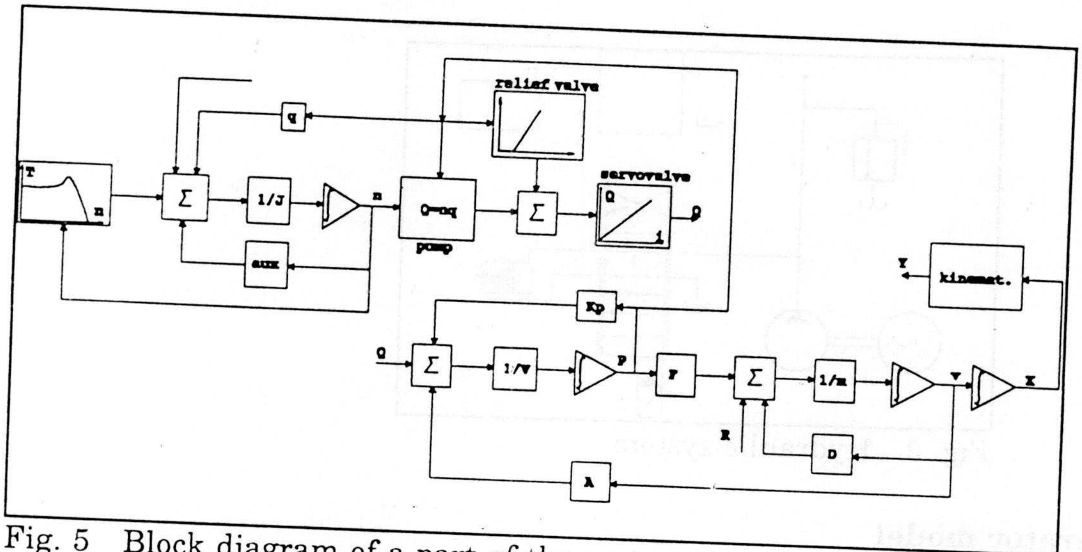

Fig. 5 Block diagram of a part of the system

tained the bang-bang control width.

The first aim, to verify a model of human operator, has been achieved, obtaining a positioning precision about 0.005 rad. for every link, which gives an error about 9mm for the boom and near one mm for the piston positioning: these results meet the results carried-out by Kuczmarski and C.

Also second aim has been obtained, to find possible problems, for exemple it isn't possible to use the continuity equation of ciylinder, when the valve return pressure is near zero, because the return pressure becomes negative by bang-bang control action, then we have replaced the continuity equation by the following

$$\frac{dp}{dt}=\frac{Ah_1\ddot{\theta}_1\cos(\theta+\phi)}{k_p}$$

where we have the piston area multiplied by piston acceleration, carried out from link acceleration, divided by flow-pressure valve coefficient (the return part of the valve).

6. References

F. Kuczmarski , T. Przychodzien, Accuracy of earthwork carried out by single buchet excavator, 3rd ISTVS European Conference, 15-17 September 1986

R. Sutton, Modeling Human Operators in Control System Design, RSP-John Wiley Inc., 1990

B. Paul, Kinematic and Dynamics of Planar Machinery, Prentice-Hall Inc.

H.E. Merritt, Hydraulic control System, John Wiley & Song Inc. 1967