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Optimal Design of an Electro-Pneumatic Automatic Transfer System

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ABSTRACT

This paper presents a method of optimal design of an automatic transfer system which is controlled by the electro-pneumatic servo scheme. The electro-pneumatic automatic transfer system can move parts to desired points or displace defective parts. The dynamic performance of the system can be examined by observing the behavior of the output. The output of the servo control system is the motion of the cylinder, pneumatic actuator. The dynamic performance of the cylinder is governed by the parameters of the components of the entire system. The optimal design can be accomplished by selecting of the parameters such that the desired dynamic performance of the cylinder is obtained.

The optimal set of parameters might be obtained through the repeated simulations. Repeated simulations, however, is not effective to determine the optimal set of parameters since the set of parameters is large. This paper presents modeling, application of an optimization method, and the numerical results. The optimization algorithm utilizes the concept of the conjugate gradient method. The results show that the suggested optimization scheme can render faster convergence of iteration compared to other method based on an algebraic optimization method and can reduce the design efforts.

1. INTRODUCTION

An automatic parts transfer system is needed for the fast moving of components or products for factory automation. Pneumatic systems have been widely used for the automatic parts transfer system since the pneumatic energy is clean as well as economic and easy to integrate with the electronic system.

The eletro-pneumatic system discussed for this paper consists mainly of parts transfer components and parts sensing components. The parts transfer components make the pneumatic systems and parts sensing components make the eletronic systems. Two systems are combined to work together. The block diagram of the system is shown in Figure 1.

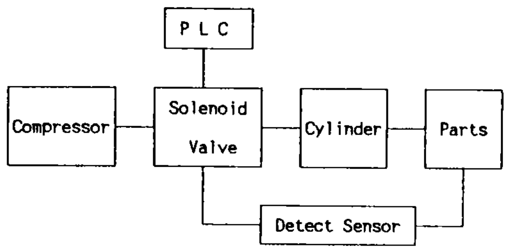

Fig. 1 Block Diagram of the System

The parts are first introduced to the system and can be distinguished by the sensor installed in the line. And the parts are then transfered to the next step. The parts are to be distinguished as either part A or B depending on their sizes. Transfering of the parts are done by the pneumatic actuators. The pneumatic components are controlled by the solenoid valve which is connected to the sensors.

The optimal design of the system can be described in several manners. This paper concerns the resonable selection of the system parameters so that a desired dynamic performance can be obtained. Some parameters are given or not selectable since they are determined from the standing point of view of the static design. Therefore, selection of the parameters can be applied to several parameters that are critical to the dynamic performance.

2. OPTIMIZATION OF DESIGN

2.1 System Configuration

The parts transfer system uses four single acting cylinders to move parts from one place to another. Each cylinder is controlled by the solenoid valve and the speed reducing valve is installed between the cylinder and the solenoid valve. Each cylinder has the same configuration with the same components and therefore the whole system can be divided into four identical pneumatic system. The pneumatic circuit diagram applied for this system is shown in Figure 2.

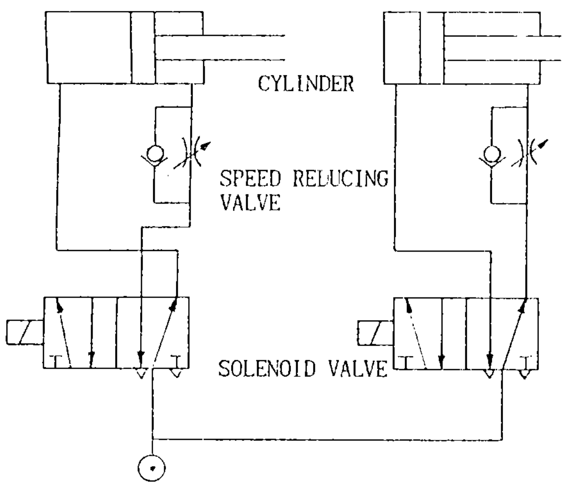

Fig. 2 Pneumatic Circuit Diagram

The electronic parts consist of the sequence citcuits with PLC(Programmable Logic Controller) and the detect sensor. The PLC gives the control signal to the solenoid valve and is programmed for the sequential motion of the cylinders. The sensor is an ultrasonic sensor and uses the piezoelectric effect. It detects the presence of the parts or determines the sizes of the parts. The structure of the sensor is shown Figure 3. If the part passes the space between the transmitter and the receiver of the sensor circuit, the ultrasonic wave is blocked and the corresponding relay is switched on. And then the signal goes to the PLC and the solenoid can be switched.

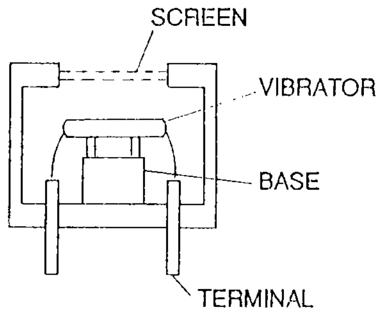

Fig. 3 Structure of Ultrasonic Sensor

2.2 System Modeling

The combined system has two parts and each has different dynamic characteristics. The electronic parts show a lot faster response compared to the pneumatic parts and therefore the dynamic equation of eletronic parts can be neglected. The pneumatic valve has the following linearized valve characteristics.

$$Q_1 = k_1 u + k_2 P_1 \qquad (2.1)$$

$$Q_2 = k_1 u - k_2 P_2 \qquad (2.2)$$

where Q's are the flow rates, k's are the valve coefficients, u is the input to the system, P_1 is the pressure in the line between the valve and the piston side of the cylinder, P_2 is the pressure in the line between the rod side of the cylinder and the valve.

The fluid continuity gives following equations:

$$\dot{P}_1 = \frac{\beta}{v_1}[Q_1 - c_p(P_1 - P_2) - a_p \dot{y}] \qquad (2.3)$$

$$\dot{P}_2 = \frac{\beta}{v_2}[a_p \dot{y} + c_p(P_1 - P_2) - Q_2] \qquad (2.4)$$

where β is the bulk modulus of the compressed air, v's are the volume involved, c_p is the leakage coefficient of the cylinder, a_p is the area of the cylinder head, and y is the position of the cylinder rod.

Equation of motion for the moving parts of the cylinder is also written as

$$\dot{y}=\frac{1}{m}[a_p(P_1-P_2)-f_l-b_f y] \quad (2.5)$$

where f_l is the external force acting onto the cylinder, m is the equivalent mass of cylinder and b_f is the viscous friction coefficient.

2.3 Variational Approach

Applying the calculus of variations to the system equations yields to a set of adjoint equations derived from the state equations as follows:

$$\frac{d\lambda_1}{dt}=\lambda_1\frac{\beta}{v_1}(c_p-k_2)-\lambda_2\frac{\beta}{v_2}c_p-\lambda_4\frac{a_p}{m}$$

$$\frac{d\lambda_2}{dt}=-\lambda_1\frac{\beta}{v_1}(c_p-k_2)+\lambda_2\frac{\beta}{v_2}c_p+\lambda_4\frac{a_p}{m}$$

$$\frac{d\lambda_3}{dt}=-\lambda_2\frac{\beta}{v_2}a_p \quad (2.6)$$

$$\frac{d\lambda_4}{dt}=-1-\lambda_3+\lambda_4\frac{\beta}{m}$$

where λ's are the Lagrangian multipliers that are to be integrated together with the state variables.

The gradients for the parameters can be written as

$$\frac{\partial I}{\partial p_1}=-\lambda_1\frac{1}{v_1}[Q_1-c_p(P_1-P_2)-a_p y]$$

$$-\lambda_2\frac{1}{v_2}[-Q_2+c_p(P_1-P_2)+a_p y] \quad (2.7)$$

where I is an objective functional to be minimized and p_1 is the parameter to be selected so that the functional has the optimal value. The functional can be given as several forms and has been defined here as being of absolute difference between the desired response and the expected response. Equation (2.7) indicates the amount of descent in the direction of optimal parameters.

Now the parameter to be optimized has been chosen as the flow gain k_1 of the control valve. The small change of flow gain gives distinct change of dynamic performance. Also, repeated simulations do not ensure to figure out the value of the flow gain for the desired response.

2.4 Numerical Algorithm

The derivative given by Equation (2.7) describes the decrease of the objective functional I when the parameter is changed in an iterative manner using its gradients. Algebraic conjugate gradient method can be adapted for the numerical algorithm.

The equations used for the conjugate gradient method is given as

$$p_{i+1}=p_i+\alpha_i g_i \quad (2.8)$$

where α_i are the positive scalars that define the distance between p_i and p_{i+1} along the gradient vector g_i. A numerical approach is required to determine α_i.

When three points are given for an algebraic function, the minimum value of the function can be determined by quadratic interpolation. Similarly, if there three different values of α_i are chosen, three corresponding values of I can be calculated by simulation of the original set of state equations. This set of α_i and I will give the point of α_i that minimize the objective functional. Initial values of α_i may be chosen that have positive values.

Even though the above approach needs more simulations at each iteration in the optimization process, the overall computation time can be reduced compared to the simple gradient algorithm.

The optimization process can be summarized as follows:

(1) Choose an initial value of the parameter within the available boundary.
(2) Evaluate the state variables by integrating the state equations.
(3) Evaluate the Lagrangian multipliers by integrating the adjoint equations.
(4) Compute the gradient.
(5) Calculate the new value of parameter.
(6) Repeat the step (2) with the new parameter value.
(7) Determine the best value of α_i through quadratic interpolation.
(8) Update the value of parameter.
(9) Check if the parameter converges.
(10) Repeat step (2) through (9) until

convergence is obtained.

3. RESULTS AND CONCLUSIONS

3.1 Results

Before the method of optimal design is applied, ordinary simulation was done to show the advantage of the optimization. The simulation gives the response of the speed of the cylinder, $\dot{y}$, which is shown in Figure 4. For the simulation, following parameter values were used:

k_2 : pressure-flow coefficient(-0.001 lbf.ft/sec) (3.1)
c_p : viscous friction coefficient (1x10^{-5} lbf ft/sec) (3.2)
f_l : external force (0.2 lbf) (3.3)
v_1 : volume 1 (10 ft^3) (3.4)
v_2 : volume 2 (10 ft^3) (3.5)
a_p : area of cylinder (0.01 ft^3) (3.6)
m : equivalent mass of cylinder (0.6 lbm) (3.7)

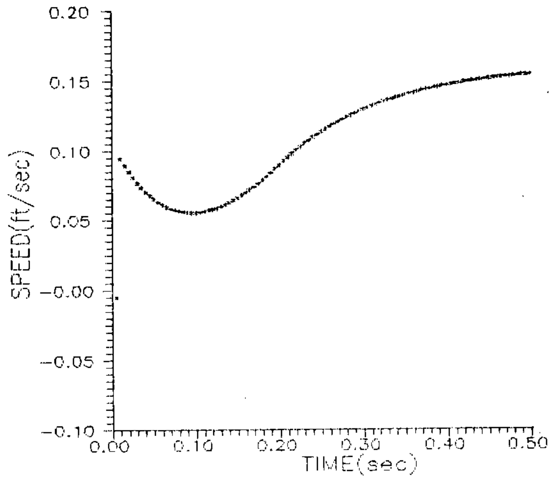

Fig. 4 Speed of Cylinder

Now the optimization was done using the method discussed above and tabulated results are shown in Table 1.

Table 1 Selective Results of Iterations

no. of iteration	value of k_1
1	100
3	91
7	67

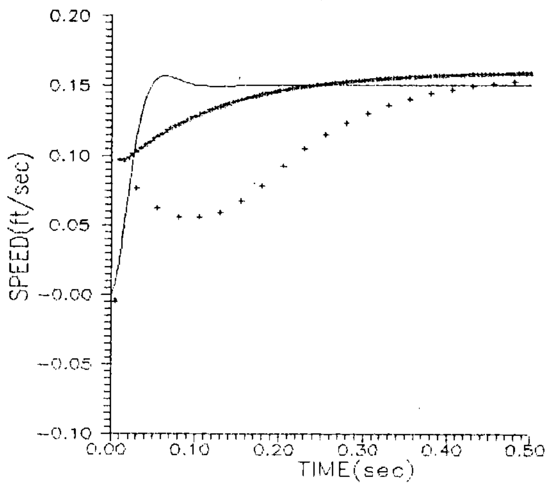

Fig. 5 Optimization Results

By following the procedure mentioned in the previous section, it is shown that the predicted response converged to the desired response. Figure 5 shows the results. The desired time response of $\dot{y}$ was given as a very fast and high damped system response, which is depicted as the solid line. The response for the initial guess of the parameter is the sparsely dotted line. The optimized result is shown as the thick line.

3.2 Concluding Remarks

The optimal design presented here can reduce the design efforts. The use of the conjugate gradient method speeds up convergence.

A limitation of the algorithm is that optimization itself can show poor convergence depending on the starting values and some other factors. Local minimum however can be a good solution. The optimization procedure sometimes might make the iteration tedious and several tips here are suggested. When iteration does not give satisfactory convergence, different starting values of the parameters can be tried.

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