Optimizing Extension and Retraction Velocities for Double Acting Cylinder Using Taguchi Method

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***Abstract*— Hydraulic actuators have a wide range for industrial applications, making them an attractive rescarch point for engineers and rescarchers to improve existing ones and/or to develop new ones with high performance levels. the improvement of existing onces can be achieved by optimizing operation parameters for optimal responses. In this study, Taguchi design of experiment (DOE) L_9 orthogonal arrays (OA) with 3-levels and 3-factors (hose length, lifting load, and pressure) are carried out to investigate the affects of operation parameters on performance measurement of actuator velocities for double acting cylinder. The analyses of signal-to-noise ratio (S/N) and variance (ANOVA) are employed to determine the optimal operation for optimal extension and retraction velocities. The obtained results show that actuator extension and retraction velocities are significantly incresed to 195.7 mm/s and 215.1mm/s (3.4 and 1.8 times higher), when compared with the initial conditions of 57.1mm/s and 120.4mm/s respectively. This significant improvement on velocities enhances hydraulic actuator efficiency and thus longer service life time for this set of experiments.**

Keywords—Optimizing Extension and Retraction Velocities; Double Acting Cylinder; Taguchi Method; Hydraulic System

I. Introduction

Hydraulic actuators have been used to control and transmit power in several industrial applications such as mobile hydraulic, wind turbines, medical equipments, aerospace, etc. Hydraulic actuators are devices used to convert pressure energy of the fluid into mechanical energy. Hydraulic cylinders extend and retract a piston rod to give a push or pull force to drive the external load along a straight-line path. Several studies have been carried out such as hydraulic pitch system which is a very important part of the modern wind turbine, continually fine-tuning the angle of the blades to the wind to optimize the wind turbines energy production. In normal operation the positioning of the hydraulic actuator motions can be executed sensitively and slowly to minimize stressing of the materials, while in extreme conditions they are performed suitably quickly to prevent damage to the turbine [1, 2]. Xue et al. [3] reported a new kind of cylinder with variable effective area, in which the cylinder can adjust the effective area with the change of the load force and allow energy recovery to reduce throttling losses. Optimization of hydraulic cylinder design used for container lifting device using Genetic Algorithm has been reported by Shah and Upadhyay [4]. Their research work presents the use of different optimization techniques used for the optimization of hydraulic cylinder. These techniques are used to solve a three objective optimization problem in which a hydraulic cylinder is to be designed. It reflects mainly two techniques of Genetic Algorithm using MATLAB single and multi-objective optimization with several constraints. Different two dimensional parametric Pareto-optimal plots are obtained for the conflicting objectives like material stress, force on piston, cylinder wall thickness and cross-sectional area of the cylinder. This optimization analysis strengthens and extends the results suggested by their previous works.

Taguchi [5] design of experiment (DOE) is a methodology for improving the quality of products and processes. Taguchi method has applied the concept of orthogonal array (OA) to minimize the number of parameters combinations that reduces the number of experiments at a lower cost and shorter times. Recently, several studies were reported by applying Taguchi design of experiments in the field of materials and manufacturing processes to determine the effect of process parameters on performance measurements (properties). Hatab et. al [6-10] investigated the effects of process parameters on removal process, friction welding, heat treatment, dental amalgam, stretching process, heating and cooling loads, and determine the optimal responses for a specific set of experiments. In this study, the application of Taguchi design of experiment is carried out to investigate the affect of the operation process parameters on extension and retraction velocities for double acting cylinder of hydraulic system.

II. Experimental Procedure and Design

A. *Hydraulic System*

The main component of the hydraulic system shown in Fig. 1, are the oil-hydraulic station (tank), double acting cylinder (hydraulic actuator) with adjustable load, 4/3 directional control valve and flexible hoses. The double acting cylinder has 25mm diameter bore, 14mm diameter rod and 200mm length.

B. Operation

Operation of the hydraulic system is quite simple. Set 4/3 directional control valve in central position, then adjust the pressure to desired values on the pressure gauge. When the directional valve is in parallel position it starts the control of the extraction; when the directional valve is in cross position, it will start the control of retraction. By varying the lifting load on the cylinder, it is noticed that the same load can determine a lower or higher acceleration of the piston rod during the extension or retraction, as a load in-direction or reverse-direction to the hydraulic push as shown in Fig.1b. The measurement of time was done using two electro mechanical limit switches and interface unit Mod.MFI-U/EV (Elettronica Veneta). The interface unit connected to the computer allows the link with the two electro mechanical limit switches for the data acquisition and monitoring by the software Visual Designer.

C. Design of Experiments.

In this research paper, the hydraulic system parameters considered are three factors with three levels for each factor, namely, pressure, lifting load, length of flexible hoses. Thus, standard Taguchi [5] design of experiment (DOE) of L_9 (3^4) orthogonal array is selected to investigate the combinations of hydraulic system parameters on extension and retraction velocities. The influence of interaction between control parameters is neglected. Table 1 and Table 2 give standard Taguchi DOE and hydraulic process parameters, respectively.

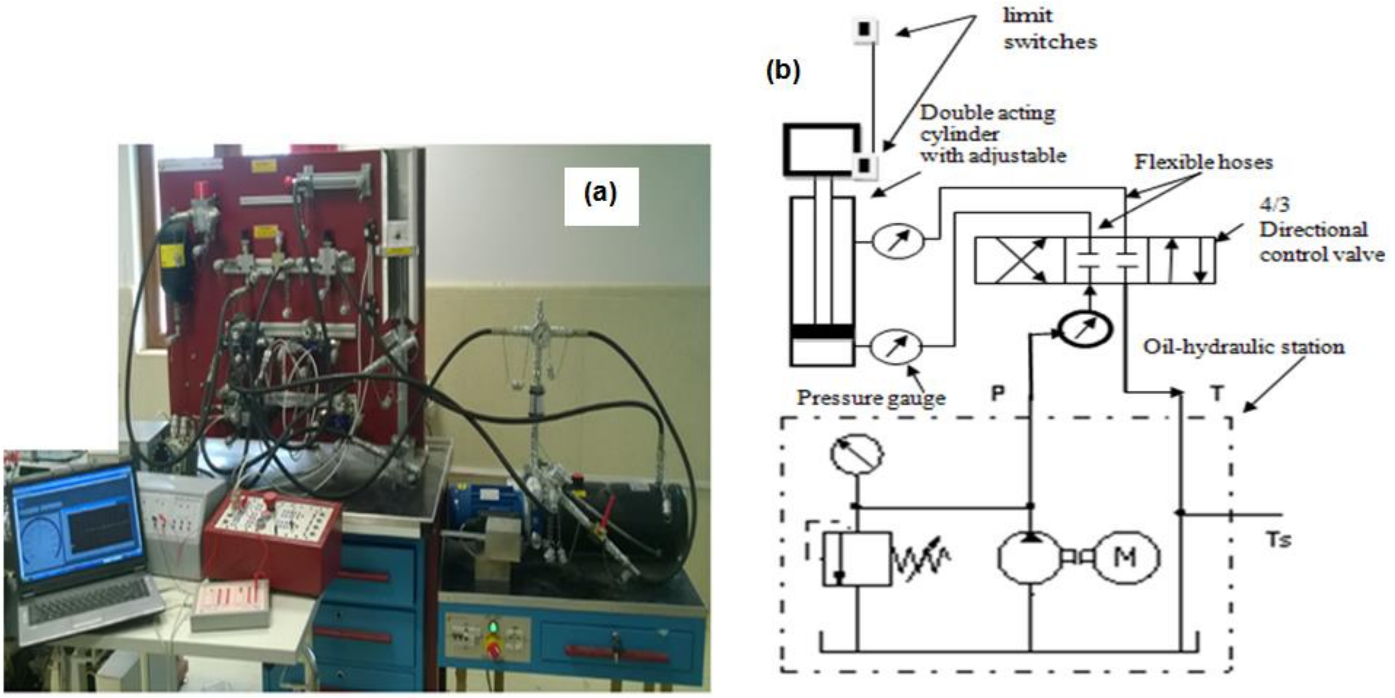

Fig. 1. Shows (a) experimental set up, (b) experimental diagram

TABLE 1. A STANDARD TAGUCHI L9 (34) ORTHOGONAL ARRAYS [5]

Experiment number	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

TABLE 2. HYDRAULIC PROCESS PARAMETERS AND THEIR LEVELS FOR DOUBLE ACTING CYLINDER

Factors	Level 1	Level 2	Level 3
A Length of flexible hoses (mm)	900	1500	3000
B Lift Load (kg)	7	14	21
D Pressure (bar)	15	30	45

III. RESULTS AND DISCUSSION

A. Taguchi Approach

Taguchi method [5] suggests the use of signal-to-noise (S/N) ratio. The S/N ratio is treated as a response of the experiment, which affects the amount of variation present within a trial. There are usually three categories of performance characteristic in the analysis of the S/N ratio: lower-is-best (LB), nominal-is-best (NB), and higher-is-best (HB). The higher S/N ratio value no matter the category of the performance is corresponding to the best performance characteristic. Thus, the optimal level of the process parameters is the level of the highest S/N ratio. The following equations give the calculations of S/N ratios for LB, HB, or NB:

$$(S/N)_{L.B} = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \quad (1)$$

$$(S/N)_{H.B} = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} \frac{1}{y_i^2}\right] \quad (2)$$

$$(S/N)_{N.B} = -10\log V_e \quad (3)$$

where r is the number of measurements in the trial, and y is the i^{th} measured value in a row, and V_e is the variance. The measured extension and retraction velocities are treated as the higher-is-best (HB) quality characteristic using equation (2).

B. Extension Velocity

The experimental results for extension velocity and the calculated S/N ratios are given in Table 3, and Fig. 2. It is evident from the results in Table 3, indicating that experiment number 3 gives the best extension velocity among the nine running experiments, while the analysis of signal - to- noise ratio shown in Fig. 2, specify that the most influence factors on extension velocity is the pressure followed by length of flexible hoses and the least affected factor is lifting load. Also, the results illustrate that the higher extension velocity is attributed to the shorts hose length (900mm or level 1), medium lifting load (14kg or level 2) and higher pressure (45 bar or level 3). The variation of extension velocities on trials may be related to pressure losses and vibration during operation.

C. Retraction Velocity

Table 4 shows the obtained results for retraction velocities, indicating that experiment number 3 represents the best running experiment. It is clearly evident from Fig. 3, that the best obtained retraction velocity is due to length of flexible hose (1500 or level 2), lifting load (21kg or level 3) and pressure (45bar or level 3). The obtained results give the most affected factors on retraction velocities are the pressure followed by lifting load and length of flexible hoses.

D. Analysis of Variance (ANOVA)

Analysis of Variance (ANOVA) is used to determine the effect and contribution of each paramter for the obtained results. The calculation of ANOVA [5] can be obtained based on the total sum of the squares (SS_T) from the total mean of S/N ratios, and given by equation (4):

$$SS_T = \sum_{i=1}^{m}(S/N)_i^2 - \frac{1}{m}\left[\sum_{i=1}^{m}(S/N)_i\right]^2 \quad (4)$$

where m is the total number of experiments, and (S/N) is the i^{th} calculated value in a row. The sum of squares due to each parameter (SS_p) is given by equation (5):

$$SS_p = \sum_{j=1}^{q}\frac{((S/N)_j)^2}{q} - \frac{1}{m}\left[\sum_{i=1}^{m}(S/N)_i\right]^2 \quad (5)$$

where the subscript ($_p$) represents one of the experiment parameters (A,B, or D), j^{th} level number of the specific parameter, q is the repetition of each level of the parameter. The percentage (P) of the contribution of each parameter to the results is obtained using equation (6):

$$P = \frac{(SS)_p}{(SS)_T} x100 \quad (6)$$

The obtained ANOVA results are given in Tables 5 and 6 for extension and retraction velocities respectively. Table 5 gives the highest contribution factors to the extension velocity is pressure with 95.3% followed by hose flexible Length with 3.5%. The contribution factors for retraction velocity are given by pressure with 80.9%, followed by lifting load with 11.3% and 5.6% hose length as shown in Table 6. The analysis of ANOVA indicates that the most affected factor is the pressure followed by hose length and least influenced factor is the lift load for extension velocities, while the retraction velocity is affected by pressure followed by lifting load and hose length which is consistent with the analysis of signal-to-noise (S/N) ratio.

E. Confirmation Experiment

After obtaining the optimal levels of control parameters, the confirmation test is the final step in Taguchi design of experiment, which is performed to verify the improvement of the quality characteristic using the optimal levels of parameters. If the confirmation test equation does not predict results of various combinations of control parameters, then a new Taguchi DOE is required. The predicted (S/N) ratio using the optimal levels of the process parameters can be determined using equation (7):

$$(S/N)_{predict} = (S/N)_{mean} + \sum_{i=1}^{n}[((S/N)_{opt})_i - (S/N)_{mean}] \quad (7)$$

The running experiment number 9 (A3B3D1) is selected for comparison purpose. It is shown in Table 7 Taguchi design of experiment can be used to improve hydraulic system (double acting cylinder) by 3.4 times higher for extension velocity and 1.8 times higher for retraction velocity when compared with experiment number 9.

TABLE 3. EXPERIMENTAL RESULTS OF EXTENSION VELOCITY AND S/N RATIOS FOR DOUBLE ACTING CYLINDER

Experiment number	Length of flexible hoses (mm)	Lifting Load (kg)	Pressure (bar)	Extension velocity (mm/s)				S/N ratio
1	900	7	15	76.989	77.467	78.938	81.517	37.918
2	900	14	30	191.879	170.852	175.664	183.414	45.086
3	900	21	45	170.852	173.224	186.152	197.971	45.157
4	1500	7	45	180.182	170.940	178.571	176.991	44.949
5	1500	14	15	76.628	74.074	77.519	72.727	37.520
6	1500	21	30	178.571	160.112	173.913	166.667	44.590
7	3000	7	30	176.678	142.450	134.228	171.086	43.691
8	3000	14	45	164.473	176.678	159.109	169.923	44.455
9	3000	21	15	55.556	51.110	59.329	62.480	35.052

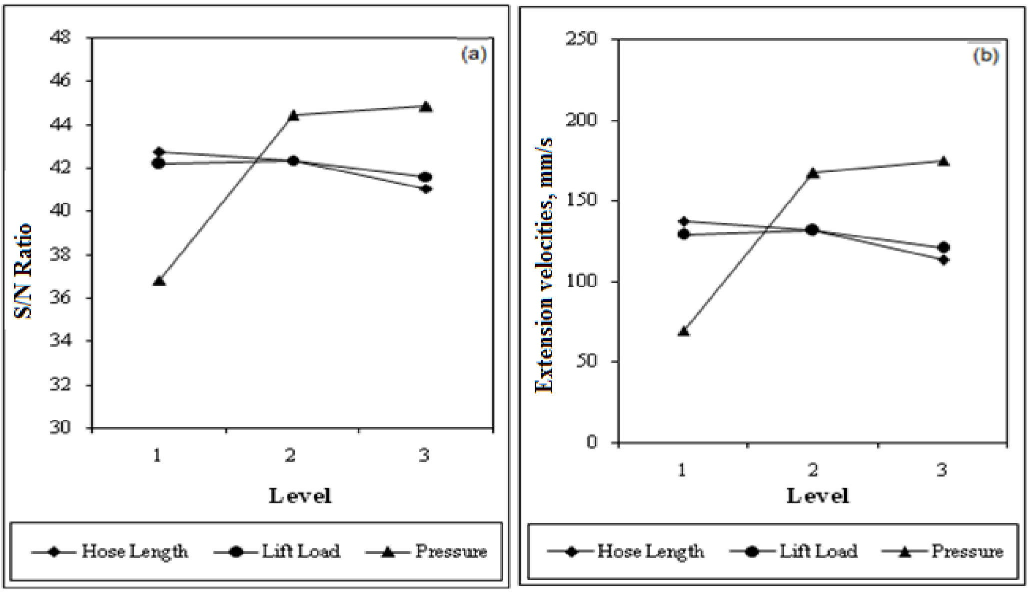

Fig. 2. Plots showing the mean effects of response for double acting cylinder, (a) S/N ratios, (b) Extension velocities

TABLE 4. EXPERIMENTAL RESULTS OF RETRACTION VELOCITY AND S/N RATIOS FOR DOUBLE ACTING CYLINDER

Experiment number	Length of flexible hoses (mm)	Lifting Load (kg)	Pressure (bar)	Retraction velocity (mm/s)				S/N ratio
1	900	7	15	92.386	91.038	98.206	101.400	39.598
2	900	14	30	188.972	204.461	183.414	218.810	45.912
3	900	21	45	215.037	211.393	235.324	201.869	46.712
4	1500	7	45	197.980	201.164	226.767	196.080	46.212
5	1500	14	15	127.267	131.286	137.057	135.567	42.453
6	1500	21	30	180.756	204.460	194.878	211.392	45.882
7	3000	7	30	146.520	132.626	140.154	168.067	43.239
8	3000	14	45	193.610	192.678	174.520	208.768	45.631
9	3000	21	15	114.090	117.508	123.076	126.984	41.591

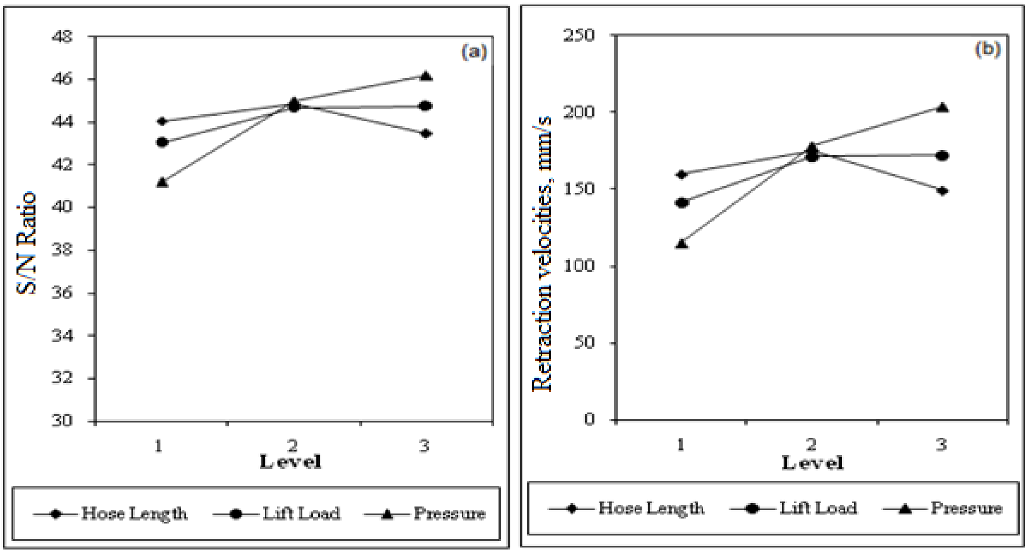

Fig. 3. *Plots showing the mean effects of responses for double acting cylinder, (a) S/N ratios, (b) Retraction velocities*

TABLE 5. RESULTS OF THE ANOVA FOR EXTENSION VELOCITIES OF DOUBLE ACTING CYLINDER.

Factors	Degrees of freedom (DF)	Sum of squares (SS)	Contribution Percentage (%)
A-Hose Length	2	4.529	3.5
B-Lift Load	2	0.941	0.7
D-Pressure	2	122.693	95.3
Error	2	0.613	0.5
Total	8	128.776	100

TABLE 6. RESULTS OF THE ANOVA FOR RETRACTION VELOCITIES OF DOUBLE ACTING CYLINDER.

Factors	Degrees of freedom (DF)	Sum of squares (SS)	Contribution Percentage (%)
A-Hose Length	2	2.800	5.6
B-Lift Load	2	5.659	11.3
D-Pressure	2	40.522	80.9
Error	2	1.130	2.2
Total	8	50.111	100

TABLE 7. CONFIRMATION RESULTS FOR EXTENSION AND RETRACTION VELOCITIES OF DOUBLE ACTING CYLINDER

Conditions	Levels	Average Actuator Extension Velocity mm/s	Average Actuator Retraction Velocity mm/s
Initial	A3B3D1	57.119	120.414
Prediction	A1B2D3	195.767	215.097
Running Experiments	A1B3D3	182.050	217.406
Running Confirmation Experiments	A1B2D3	195.769 192.464	212.416 212.095
Improvement	A1B2D3/A3B3D1	3.4 times higher	1.8 times higher

IV. Conclusions

The present research paper reveals the application of Taguchi design of experiment for optimizing extension velocity or retraction velocity as a single quality response to efficiently establishing hydraulic actuator process parameters of double acting cylinder. The results show that the optimal parameters of the hydraulic actuator are A1B2D3 (900mm, 14kg, 45bar) for the extension velocity and A2B3D3 (1500mm, 21kg, 45bar) for the retraction velocity, and the most influence parameter is the pressure. Also, the obtained results show that extension and retraction velocities are improved by 3.4 and 1.8 times higher respectively when compared with the initial condition and the confirmation test equation can be used to predict results of various combinations of control parameters for this specific set of the experiments.

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