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Design of basic chamber of the Main Control Valve

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Analysis and modelling

ABSTRACT

Purpose: The development of a control valve for closed circuit requires comprehensive technologies in the overall precision machinery industry, from the development of casting materials for the housing to various types of parts. The development of a new type of control valve would have great advantage with a long lifecycle. Therefore, it is necessary to secure the MCV (Main Control Valve) development technology that applies various sensors. This paper aims at providing a fundamental base for the establishment of design systems including the flow chamber design database of the MCV for wheel loaders, strength and rigidity design system, and the system for energy efficiency improvement. Particularly, this study set up the basic design database for the flow chamber design to establish the flow chamber design database, and secured the stability of the flow chamber from the basic design stage. In addition, major design variables were determined by utilizing a statistical technique in order to design such flow chamber.

Design/methodology/approach: This study uses the I-DEAS to analyze the MCV structure characteristics. In addition, it uses the factorial design and sensitivity analysis to select important factors for the MCV design.

Findings: This study establishes the unit flow chamber database for the MCV housing unit and the governing equation for the flow chamber.

Research limitations/implications: Since the MCV damage often occurs due to the problem with the material itself and in the manufacturing process, it is difficult to tell clearly whether it occurred as the MCV reached the failure pressure.

Practical implications: The basic data needed to design the MCV can be provided, and the required time for the design and the reliability of the design can be reduced and improved respectively.

Originality/value: The verification of the design factors obtained from the flow analysis and structural analysis as well as the DOE was made by fabricating a sample MCV and performing tests on it.

Keywords: Statistic method; Computational material science and mechanics; Design of experiment (DOE); Finite element method (FEM)

1. Introduction

The development of a closed circuit control valve requires comprehensive technologies in the overall precision machinery industry, from the development of casting materials for the housing to various types of parts, as well as the investment in time and money. In addition, the core technologies for the hydraulic control valve, including valve casting with a high degree of difficulty as well as parts machining, assembling, and testing, requires experience accumulated over a long period time and a high technological level. Even though the manufacturing process technology has reached a significantly high level, the defect rate is high and the price is high due to the weakness in the technology for the design and casting materials. Particularly, the products with high performance, which have a complicated internal flow chamber, require significantly high level technology in core fabrication, etc. for casting. Therefore, this study set up the basic design database that can provide fundamental data for the MCV design. In order to set up such database for basic design, this study established the stability and design criteria of the flow chamber and secured parameter data determining the valve shape. In addition, it designed the MCV for a sample wheel loader to execute such processes. This MCV was designed by simplifying the MCV having the flow chamber of complicated flow shape and determining the basic flow chamber shape. The database was set up by performing the design of experiments (DOE) and structural analysis in parallel [1, 2, 4, 5]. In the case of the DOE, the effect of the input variable on the output variable is examined and a mathematical model is assumed. In addition, necessary prediction or the statistical inference of interest is made. Here, the output variable was set as the maximum principal stress and the input variable as the geometrical design variable for the flow chamber. In the case of the structural analysis [3, 7], the output variable was analyzed when the fluid pressure was applied on the flow chamber consisting of geometrical design variable data for the flow chamber .

Figure 1 indicates the MCV with flow chambers of various shapes. If high pressure working fluid flows through the flow chambers, a certain fluid path may be subject to high stress due to hydraulic pressure [6, 8, 9]. If the stress created by the hydraulic pressure is less than the allowable stress of the MCV material, no abnormal symptom occurs. However, the trend toward high MCV output and compact size, which contradicts each other requiring that the flow rate and hydraulic pressure be increased while the valve size is reduced, causes significant difficulty in designing the flow chambers. Therefore, this study presents the MCV design method oriented to a smaller valve with increased flow rate and hydraulic pressure by which existing flow chambers with high possibility of damage could be easily redesigned by introducing conceptual flow chamber design that considers the stress and flow chamber shape by using the DOE so that the flow chambers satisfying the allowable stress could be designed [10-12].

2. Selection of basic flow chamber

2.1. Flat and angle type basic chamber

The MCV shown in Figure 1 consists of a very complicated flow chambers. However, even though it is composed of complicated flow chambers, if flow chambers of similar shape are deleted, they can be divided into basic flow chambers consisting of unit flow chambers.

The shape of the basic flow chambers of the MCV is divided into two shapes: the one with the flat type flow chamber contacting with each other and the other with the flat type and angle type flow chambers contacting with each other. This study set the unit flat and angled flow chambers. Figure 2 presents the design variables for the unit flow chamber.

2.2. Design variables of basic chamber

When fluid flows through the flat and angle type basic chambers as shown in the above Figure 2, if high pressure is applied to the flat chamber, the stress created in the flow chambers is different. Therefore, the main effect and interaction were examined for each case. As can be seen in Figure 2 and table 1 the design variables that express the basic flat and angled flow chambers can be divided into 12 factors as presented in Equation (1). However, this study assumed that

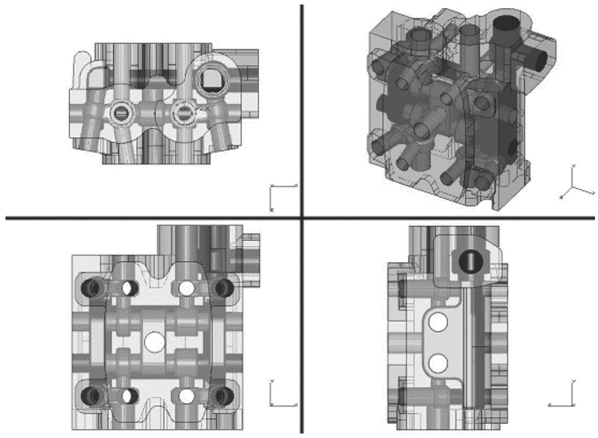

Fig. 1. Main control valve

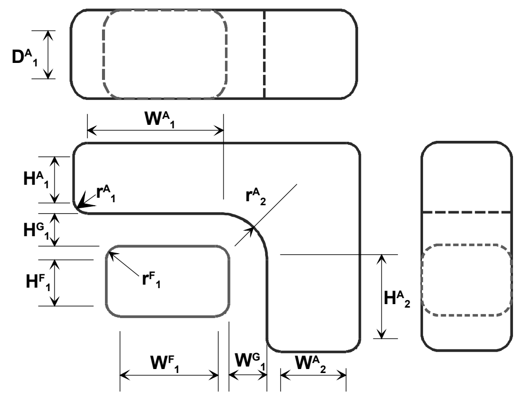

Fig. 2. Basic flat and angled flow chamber

r_1^A was equal to r_1^F in order to reduce the number of times of experiments and improve the accuracy of the structural analysis. Therefore, the design variables were divided into 11 factors in total. The fractional factorial design was applied for the factorial design of the basic chamber. In the case of the fractional factorial design, the main effect is not confounded and the secondary interaction is confounded with the tertiary interaction.

$$\sigma_{MPS}^{F,A} = f\begin{pmatrix} H_1^F, W_1^F, H_1^A, W_1^A, H_2^A, W_2^A, \\ r_2^A, r_1^F, r_1^A, D_1^A, H_1^G, W_1^G \end{pmatrix} \tag{1}$$

Table 1.
Factors and levels for basic chamber

Flat Chamber		'L' Shape Chamber					Fillet	Depth	Gaps	
H^F_1	H^F_1	H^A_1	W^A_1	H^A_2	W^A_2	r^A_2	r^A_1	D^A_1	H^G_1	W^G_1
5.0 mm	5.0 mm	5.0 mm	5.0 mm	5.0 mm	5.0 mm	5.0 mm	3.0 mm	20.0 mm	8.0 mm	8.0 mm
40.0 mm	40.0 mm	40.0 mm	40.0 mm	40.0 mm	40.0 mm	20.0 mm	7.0 mm	100 mm	14.0 mm	14.0 mm

3. Modelling for FEM

3.1. Preparing for FEM

In the case of the structural analysis of the flat and angle type basic chambers, the creation of mesh for the entire model requires exceedingly long time in performing the FEM analysis since there are too many meshes. In addition, it is difficult to expect that the reliability of the analysis result will be improved. Therefore, since each basic chamber has symmetrical structure as can be seen in Figure 3, the analysis was performed for the half model. Of the boundary conditions (Fig. 4.), the pressure applied to the interior of the chamber was set to 400 MPa (40 bar).

4. Statistical results

4.1. Normalizing of the MPS

This study examined first whether the maximum principle stress (FMPS) in the flat chamber, which was the analysis result presented in the experiment plan prepared according to the fractional factorial design, followed the normal distribution. In the case of the normal probability plot, the normal score is obtained of the given data and the scatter plot between that data and the normal score is made. The degree of verticality is similar to the vertical scale in the normal probability plot and the horizontal axis becomes the scale for the linearity. The lines indicated in the normal plot form the estimated values of the cumulative distribution function for the populations from which data is extracted. The population parameters including the estimate for the mean standard deviation, normality, test values, and associated p-values are indicated together. At this time, as the indicated aspect appears nearly straight, the data can be said to follow normal distribution. However, as can be seen in Figure 5, the aspects in which the dots appear do not form a straight line. In addition, since even the p-value is less than 0.05, it can be presumed that they do not follow normal distribution. In such

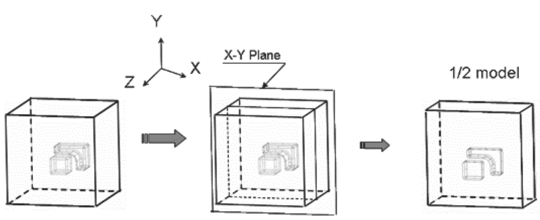

Fig. 3. Simplified for basic chamber

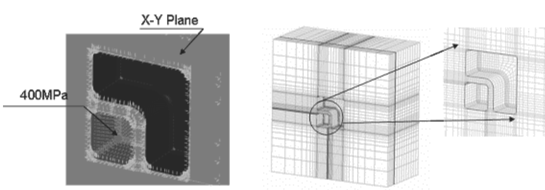

Fig. 4. Pre-processing for FEM

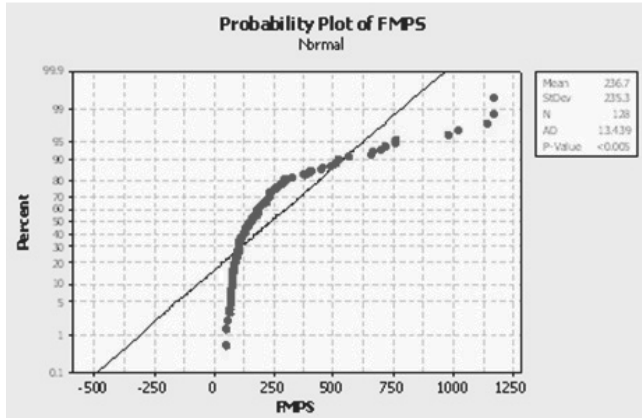

Fig. 5. Probability plot of FMPS

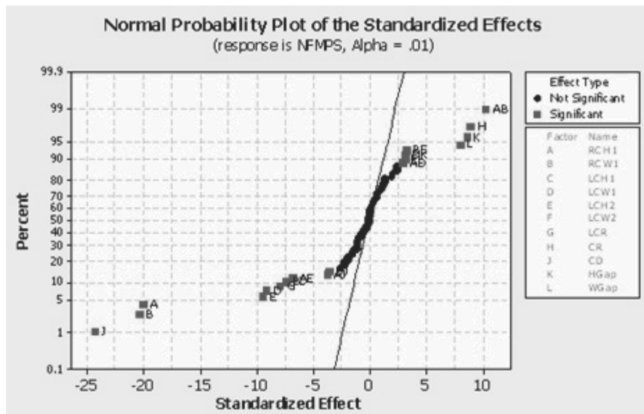

Fig. 6. Normal probability plot

case, conversion was made so that the maximum principal stress distribution follows the normal distribution by using the Box-cox conversion method. What is most important in the Box-cox conversion is to obtain λ by which original data can be modified. As a result, the optimum λ was presumed to be -0.39. However, since it made no difference whether this value is selected or -0.5 which is within the 95% reliability range of λ is selected, a value rounded off to -0.5 was selected λ for the data normalization.

4.2. Result of the FEM

This study performed factorial experimentation to investigate the main effect of the design variables for the flat and angled basic flow chamber on the normalized maximum principal stress as well as interaction thereof. A Figure 6 presents the normal probability plot respectively. In Figure 6, the dots that are not near to the line signify that they are important effects. The important effects exist farther from the appropriate line than unimportant effects and they have great values.

This study performed statistical analysis with these results. As a result, it confirmed that the significant main effects and interaction of all design variables could be explained within

94.3% of the normalized maximum principal stress. In addition, the result of the analysis of variance revealed that the sequential sum of square of the main effects accounted for 82.2% of the maximum principal stress normalized to 0.073139 while the sequential sum of square of the significant interaction was 0.010797, accounting for 12.1%. In addition, Figure 7 presents the main effects of all design variables other than H^A_1 and W^A_2, which are significant. From Figure 7 and the geometric characteristics of the flat and angled basic flow chambers, it can be seen that the main effects of H^F_1 and W^F_1 are identical.

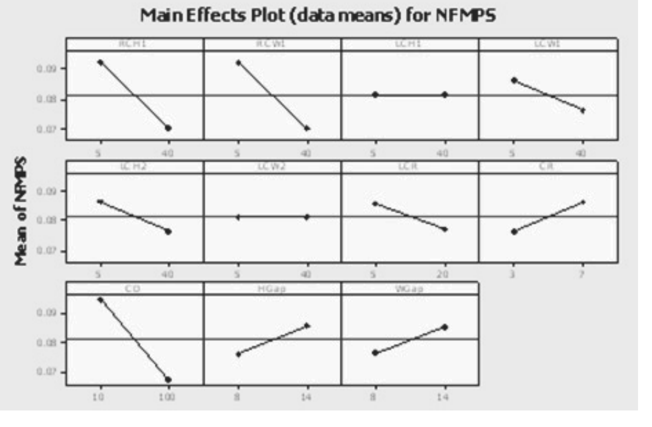

Fig. 7. Main effect of the basic chamber

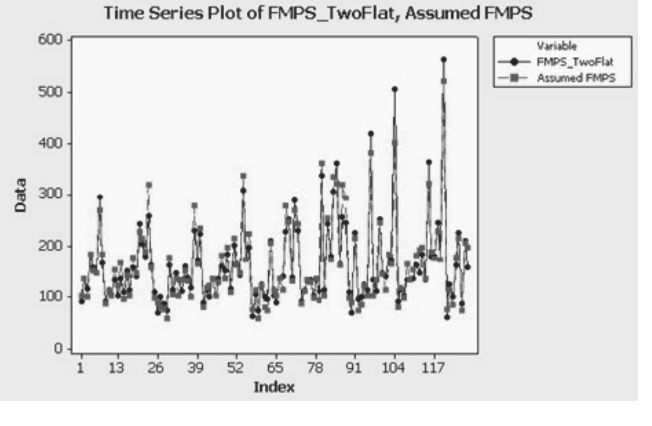

Fig. 8. Time series plot

Table 2.
Coefficient of the simple regression equation

Term	Coef (C, a_i)	Term	Coef (b_i)
Const. C:	0.113348		
H^F_1	a_1 -7.53075E-04	$H^F_1 * W^F_1$	b_1: 1.87294E-05
W^F_1	a_2 -7.67028E-04	$H^F_1 * W^A_1$	b_2: 5.40774E-06
W^A_1	a_3 -4.85701E-04	$H^F_1 * H^A_2$	b_3: -1.24397E-05
H^A_2	a_4 -5.24234E-04	$H^F_1 * D^A_1$	b_4: -2.61620E-06
r^A_2	a_5 -5.87201E-04	$W^F_1 * W^A_1$	b_5: -1.32906E-05
r^A_1	a_6 0.00248546	$W^F_1 * H^A_2$	b_6: 6.02698E-06
D^A_1	a_7 -1.85557E-04	$W^F_1 * D^A_1$	b_7: -2.43947E-06
H^G_1	a_8 0.000833531	$W^A_1 * H^G_1$	b_8: 3.39256E-05
W^G_1	a_9 0.000739255	$H^A_2 * W^G_1$	b_9: 3.36135E-05

5. Conclusions

The simple regression equation for the normalized maximum principal stress (NFMPS) can be derived into the following Equation (2) by using significant main effect and secondary interaction in the fractional factorial experiment. Here, C is constant and ai and bi (i=1~9) are coefficients, which are shown in Table 2. Figure 8 present the time series analysis according to statistical analysis results. As a result, in the case of the residuals, since they show no particular pattern and all of them exist within a certain range, it can be said that the analysis model is appropriate. In addition, it could be confirmed that in the case of the time series analysis, errors occurred to the maximum principal stress (FMPS) and predicted maximum principal stress (AFMPS) at about 500 MP and above while it worked comparatively accurately. Therefore, Equation (2) and Table 2 can be utilized as data for the basic design of the MCV.

$$\begin{aligned}\sigma^{F,FA}_{nMPS} &= C + a_1 H^F_1 + a_2 W^F_1 + a_3 W^A_1 + a_4 H^A_2 + a_5 r^A_2 \\ &+ a_6 r^F_1 + a_7 D^A_1 + a_8 H^G_1 + a_9 W^G_1 + b_1 H^F_1 W^F_1 \\ &+ b_2 H^F_1 W^A_1 + b_3 H^F_1 H^A_2 + b_4 H^F_1 D^A_1 + b_5 W^F_1 W^A_1 \\ &+ b_6 W^F_1 H^A_2 + b_7 W^F_1 D^A_1 + b_8 W^A_1 H^G_1 + b_9 H^A_2 W^G_1\end{aligned} \qquad (2)$$

References

[1] J.A. Collons, Failure of Materials in Mechanical Design, Wiley Interscience, New York, 1993.
[2] Y.C. Fung, P. Tong, Classical and Computational Solid Mechanics, World Scientific, Singapore, 2001.
[3] R.D. Mason, D.A. Lind, W.G. Marchal, Statistics: An Introduction, Harcourt Brace Jovanovich, New York, 1983.
[4] K.J. Bathe, Finite element procedures, Prentice hall, New Jersey, 1996.
[5] S.K. Ghosh, A. Niku-Lari, CAD/CAM and FEM in metal working, Pergamon Press, New York, 2006.
[6] S.A. Meguid, R.H. Mao, T.Y. Ng, FE analysis of geometry effects of an artificial bird striking an aeroengine fan blade, International Journal of impact Engineering 35 (2008) 487-498.
[7] W. Torbacki, Numerical strength and fatigue analysis in application to hydraulic cylinders, Journal of Achievements in Materials and Manufacturing Engineering 25 (2007) 65-68.
[8] Ch. Cho, W. Kim, B. Choi, S. Kwak, A finite element mesh management in casting simulation, International Journal of Computational Materials Science and Surface Engineering 1 (2007) 4-17.
[9] L.A. Dobrzański, A. Śliwa, W. Sitek, W. Kwaśny, The computer simulation of critical compressive stresses on the PVD coatings, International Journal of Computational Materials Science and Surface Engineering 1 (2007) 28-39.
[10] E. Rusinski, J. Czmochowski, P. Moczko, Numerical and experimental analysis of a mine's loader boom crack, Journal of Achievements in Materials and Manufacturing Engineering 17 (2006) 273-276.
[11] S.W. Lee, D.Y. Shin, C.W. Byun, H.J. Yang, I.C. Baek, Modified design for the poppet in check valves, Journal of Achievements in Materials and Manufacturing Engineering 23 (2007) 67-70.
[12] S.P. Timosenko, An introduction to the mechanics of solids, McGraw-Hill, New York, 1978.