Application of the Expert Systemfor Basic Design of Compressors

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ABSTRACT

Various analysis to calculate the thermodynamic efficiency, the performances of the valve systems and the acoustic characteristics of the gas manifold are integrated in one system with necessary design rules for basic design of compressors. Expert system rule bases are used to identify design problems existing in the model and to suggest directions to improve them. A case study illustrates how a typical design work can be done utilizing analysis/simulation features and design features of the system. The system can handle both rotary piston type compressors and reciprocating piston type compressors.

INTRODUCTION

The expert system is a special branch of the artificial intelligence (AI) technology that captures the experience, knowledge of an expert practitioner for use by others. Some practical applications can be found in references [1, 2, 3, 4, 5, 6]. Expert systems can be a powerful tool if they are made for a well defined specific design problem whose traditional design process is well understood. A primitive expert design system to be used for the compressor valve design has been developed by Kim [3].

The purpose of this paper is to report an application example of the expert system technology to the overall design of compressors. The system is composed of three part: utilities, analysis/simulation and the design parts. The analysis/simulation part consists of the programs for valve system analysis, thermodynamic performance simulation and gas manifold analysis. The design part consists of the valve design part and the gas manifold design part. The design part is rule base programs which evaluate existing design problems and recommend necessary suggestions. A function for sensitivity analysis has been added to the system to provide quantitative guides. Utility programs are to provide graphics capabilities and other supporting functions.

OVERVIEW OF THE SYSTEM

Figure 1 shows that the overall configuration of the compressor design expert system. The system has three major programs: valve analysis/design, compressor performance simulation and gas manifold analysis/design. Design parts are made in expert rule based systems while other parts are made in Fortran and C. Figure 2 illustrates a typical screen of the system while it is used.

In general, a design process is characterized by a sequence of the steps: 1) Building an initial model, 2) Analysis/simulation of the model, 3) Evaluation of the analysis/simulation result, and 4) Modification/redesign of the model based on the evaluation. The steps 3) and 4) are done by the expert system design rules. Figure 3 shows a typical procedure in each stage. This sequence is repeated step by step until all the design requirements are satisfied or the designer chooses the final design.

Valve analysis and design

This part is viewed to have two phases: analysis and evaluation/redesign. The analysis is done for multiple sets of prototypes which are ranked by their performances. Based on the result, the user is directed to select one design set to further evaluate it in the expert system. Details of the diagnosis/suggestions part are explained in reference [1].

Expert system part diagnoses design problems existing in the model selected by the designer and recommends necessary actions to eliminate them. The selected design is evaluated by a rule-based system to identify the causes of the problems first. Corresponding suggestions are reported in the report file created by the rule-based system as shown in Figure 4. According to these results, the designer can revise the selected design and reevaluate the performance of the revised design again. This procedure is iterated until all the criteria are satisfied or the designer selects the design as the final one.

Compressor performance simulation

This program calculates the thermodynamic performance and gas pulsations of the compressor. Calculation results can be reviewed graphically in the P-V diagram, time histories of the cylinder pressure, temperature, displacement, Mach number, and head cavity pressure. The result of this program is further analyzed to obtain the efficiency, losses and estimated flow rate as in Figure 7. Main uses of this part are to provide necessary information for other parts in the system and to evaluate the effect of the design change in detail.

Gas manifold analysis and design

The gas manifold analysis part calculates the transfer functions (pressure/input flow and output flow/input flow) of any general gas manifold design. Also, it calculates the resonance frequencies, cut off frequencies, and the amplitude of the gas pulsation in the head cavity. The gas manifold design part recommends the size of the head cavity, the cross sectional areas and lengths of pipes for the one volume muffler and two volume mufflers. Then it identifies design parameters which are most effective to change the characteristics of the cavity design so that it has a desirable characteristics. The characteristics used are the resonance frequencies, cut-off frequencies and magnitude of the resonance peaks. The design rule base also compares the existing gas manifold design with recommended design and creates the suggestions to solve the problems.

CASE STUDY

In this section a case study is shown for a reciprocating piston type compressor. Table 1 shows the results of the valve analysis for the suction and discharge sides. Based on the initial design, the relative performances of the valve system in both suction and discharge side are calculated. Here the application is shown only for the suction side of the valve, because the discharge side is done by the same procedures. Table 1 shows the analysis result of the current design (the port/valve pair (1,1)). It is the initial design selected by the designer to be tested by the expert design system to identify any existing problems. Based on the diagnoses, suggestions are made to guide the designer to improve the design. Figure 4 is a typical report from the expert system.

The report file shown in Figure 4 explains the relation between valve deflection and valve stopper, the causes of the problems and related suggestions. From the result (1,1) of the valve analysis in Table 1, it is known that the design has too restrictive valve system which causes a high Mach number. It also tells that the port area and the exit area are too small. Exit area is the area formed by the valve deflection and the valve plate. Several suggestions are made in order to improve the situation. It is suggested that the port and exit areas can be increased most effectively by increasing the length of the valve.

After the designer revised the design following to the suggestion, the analysis part evaluates this new design model again. Table 1 shows the analysis result of the design (3,3) which shows the Mach number is reduced from 2.31 to 1.74, where the value is referenced with recommended values. The value of 1 or less is considered acceptable for each criterion. Since the Mach number of the new design model is still greater than 1, this model can be selected again as a new base design model for more iterations, although no more iterations are made here.

The designer can compare the performances of the original and the new design models graphically from their simulated P-V diagram. Figures 5 and 6 show that the P-V diagram and the Mach number-angle diagram. Figure 7 shows the comparison of the simulated efficiencies of the two design models. In this case, the efficiency has been improved approximately by 7.8 %.

The procedures of the gas manifold analysis and design part are as follows: 1) Calculate the recommended size of the head cavity, 2) Calculate other dimensions (cross sectional areas and lengths of pipes) of the recommended gas manifold, 3) Compare the dimensions of the existing gas manifold with the recommended one, and 4) Select the recommended one as the final design or 5) ask the design suggestions to change the existing design. The example of the gas manifold analysis and design can be found in reference [2].

CONCLUDING REMARKS

An expert system to be used for the basic design of compressors has been developed. The scope of the system is currently limited to the valve system design and gas manifold design. The system has three types of programs, which are the analysis/simulation programs, the design rules and utility programs. The first part is to provide necessary design information for the user, and the second part is to guide the user toward better designs.

Various extensions of the current system in its scope and features are possible. For example, design work related with the compressor dynamics may be added to aid the selection of motors. Also other types of engineering efforts, such as noise measurements or shell vibration analysis, may be interfaced with the system so that necessary information can be easily exchanged and referenced with each other.

Based on our experience, two remarks are made for similar future works:

1. The main purpose of the design software should be to provide necessary analytical and logical processing power for the human designer. It is not wise to try to computerize the elements of the design which are inherently better to be done the human designer.
2. The rule base, or AI technique in general, should be used only for the part where it performs better than other tools. An example may be to make decisions subject to many conditions related with each other in complex manner.

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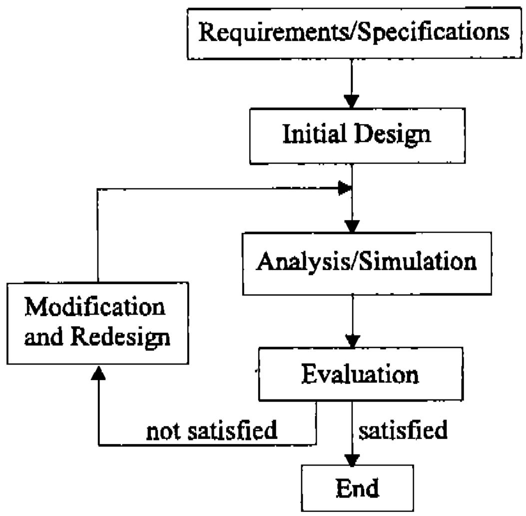


Fig. 3 Design process

Table 1 Analysis results of the reciprocating piston type

Suction side

Design	Stop	M	t_c	σ_{inf}	σ_b	v_{imp}
(1, 1)	0.81	**2.31**	0.77	0.48	0.62	0.36
(3, 3)	0.99	**1.74**	0.77	0.59	0.53	0.45

Discharge side

Design	Stop	M	t_c	σ_{inf}	σ_b	v_{imp}
(2, 2)	1.00	**2.10**	**2.95**	0.16	0.99	0.62
(4, 4)	0.85	**1.02**	**2.65**	0.42	0.86	0.59

(*, *) is (port, valve)

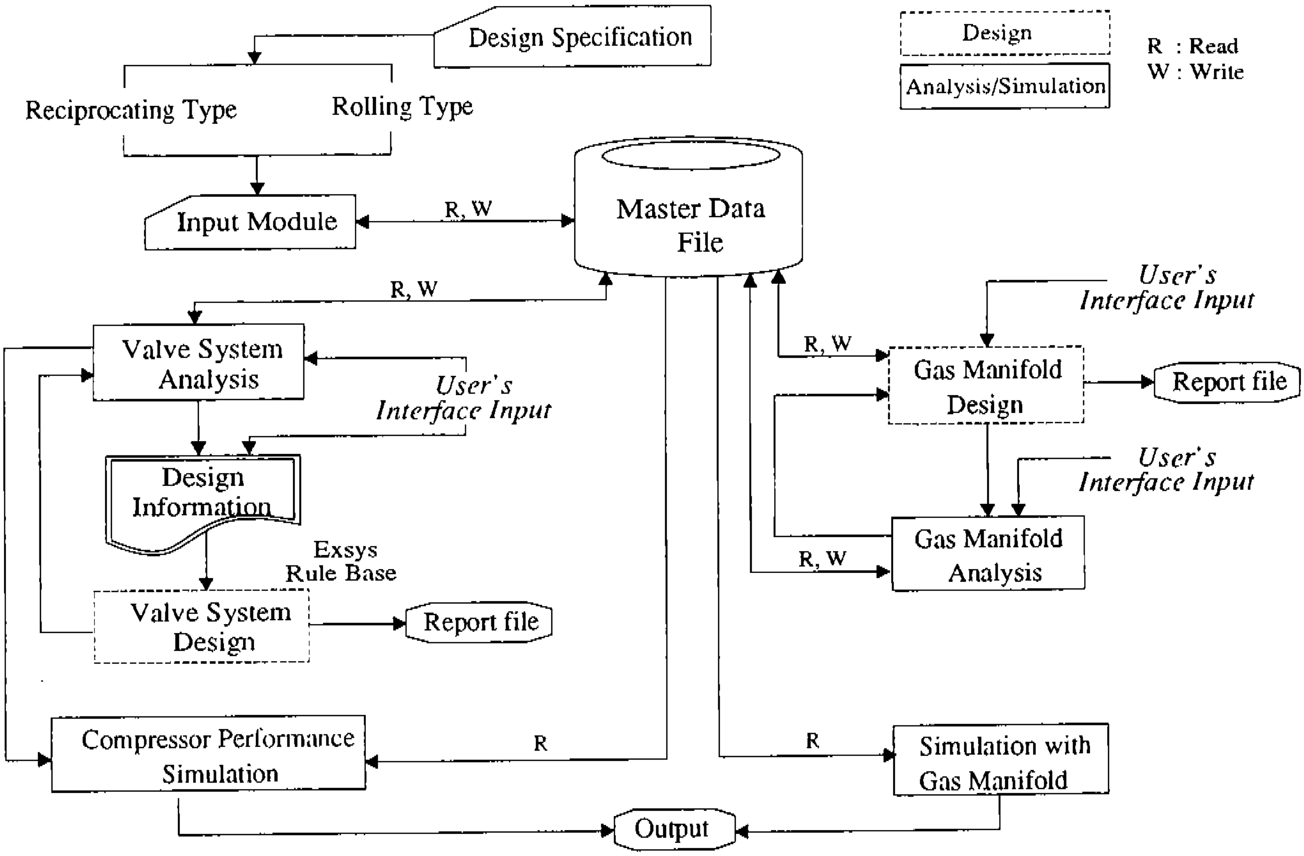


Fig. 1 Overall Configuration of System

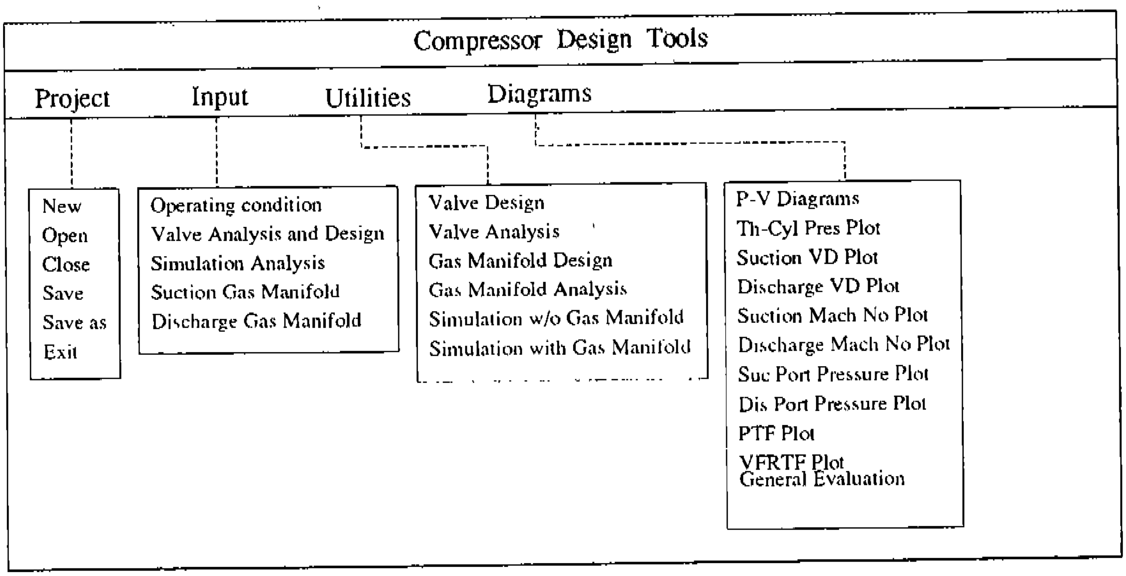


Fig. 2 Typical screen of the system

Fig. 5 P-V Diagram

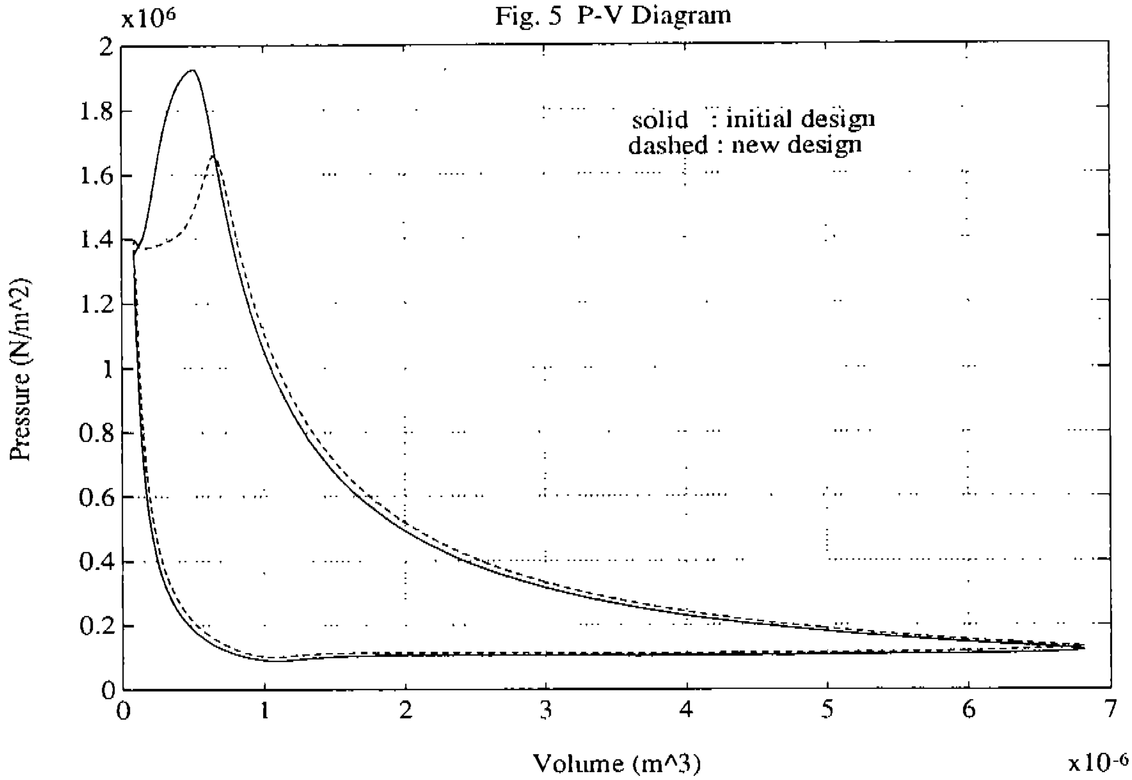
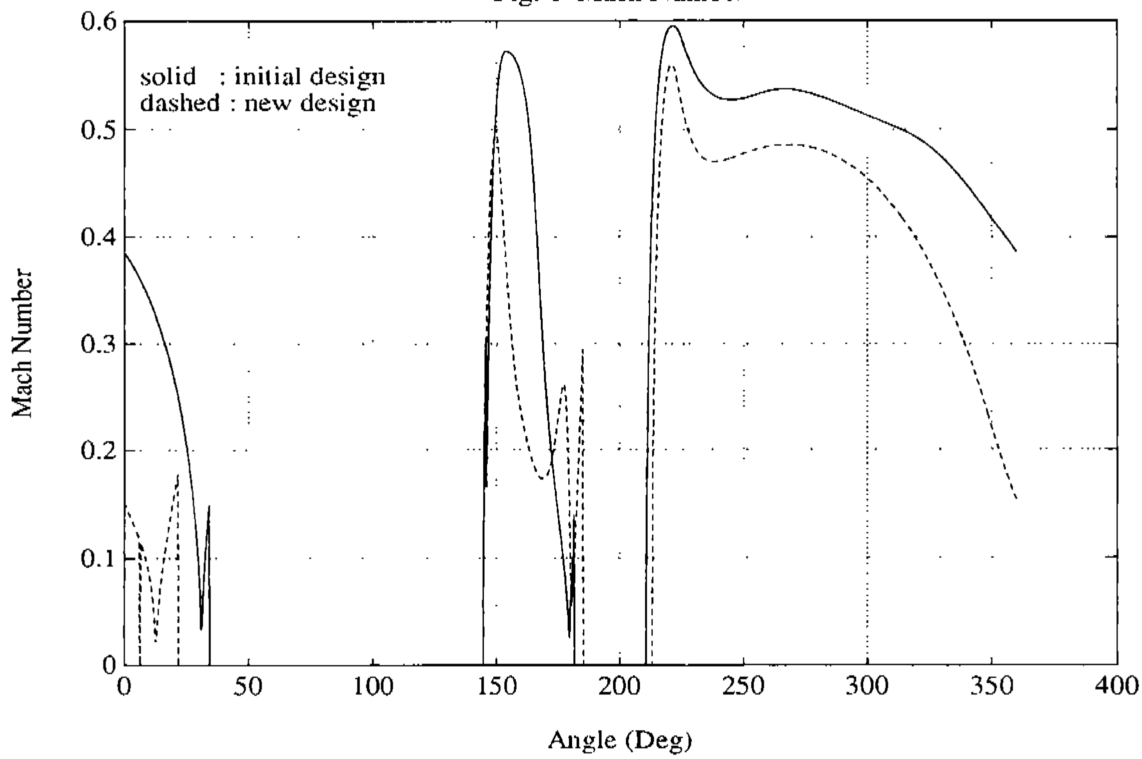


Fig. 6 Mach Number



***** REPORT OF THE ANALYSIS RESULT USING EXPERT SYSTEM *****
*** RECIPROCATING PISTON TYPE COMPRESSOR (CONNECTING ROD TYPE) ***

** The Selected Port/Valve System of the Compressor is :
THE PORT/VALVE PAIR (1,1) IS ON THE SUCTION SIDE

** Results between Valve stopper and Valve deflection
1) Valve stopper exists.
2) Valve stopper height is lower than reference stopper height.
3) Valve does not contact the valve stopper. (Not Active)
4) Valve deflection is lower than valve stopper height.

**** THIS IS THE FIRST LEVEL REPORT ****

* Mach Number (M)

1) Diagnoses :
* Mach number is too high
(1) Flow velocity is too high
(1.1) Effective flow area is too low
(1.1.1) Port area(Ao) and Exit area due to valve deflection (A1) are too low

2) Suggestions :
* Increase valve stopper height (H)
* Reduce valve stopper height (H) --- (Weak Possibility)
* To improve (1.1.1), increase port area (Ao) and exit area due to valve deflection (A1)

To increase port area (Ao),
i) Increase port size (D) --- (Weak Possibility)
If port size (D) is increased by 10 %,
then Mach number will be reduced by 9.838 %
ii) Increase number of port --------- (Weak Possibility)
To increase exit area (A1),
i) Reduce valve width (W)
If valve width (W) is reduced by 10 %,
then Mach number will be reduced by 3.116 %
ii) Reduce valve thickness (t)
If valve thickness (t) is reduced by 10 %,
then Mach number will be reduced by 8.911 %
iii) Increase valve length (L) (SS - SS)
If valve length (L) is increased by 10 %,
then Mach number will be reduced by .001 %
iv) Increase valve length (Lp) (Cantilever)
If valve length (Lp) is increased by 10 %,
then Mach number will be reduced by 8.114 %
If necessary (i.e., Lp is fully large),
then increase valve length (L) - (Cantilever)

**** END OF DIAGNOSES AND SUGGESTIONS ****

Fig. 4 Report File of Suction Side (Reciprocating Piston)

*** RECIPROCATING TYPE COMPRESSOR ***
RESULT OF THE COMPRESSOR SIMULATION

*** ORIGINAL MODEL:**

[1] THERMODYNAMIC PERFORMANCES

(1) Thermodynamic efficiency	=	82.9033 %
(2) Total loss (100 - efficiency)	=	17.0967 %
(3) Anatomy of losses		
* Discharge side loss	=	9.7991 %
discharge gas pulsation loss	=	.0000 %
discharge valving system loss	=	9.7991 %
* Suction side loss	=	7.2976 %
suction gas pulsation loss	=	.0000 %
suction valving system loss	=	7.2976 %

[2] MASS FLOW RATE
Mass flow rate per hour = .8339E+01 Kg/Hr

[3] POWER CONSUMPTION = .1903 Horse Power
= .1419 KWatts

*** NEW MODEL:**

[1] THERMODYNAMIC PERFORMANCES

(1) Thermodynamic efficiency	=	90.7240 %
(2) Total loss (100 - efficiency)	=	9.2760 %
(3) Anatomy of losses		
* Discharge side loss	=	3.8343 %
discharge gas pulsation loss	=	.0000 %
discharge valving system loss	=	3.8343 %
* Suction side loss	=	5.4417 %
suction gas pulsation loss	=	.0000 %
suction valving system loss	=	5.4417 %

[2] MASS FLOW RATE
Mass flow rate per hour = .8673E+01 Kg/Hr

[3] POWER CONSUMPTION = .1807 Horse Power
= .1347 KWatts

Fig. 7 Efficiency of Reciprocating Piston Type Compressor