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Suction Flowrate Prediction Model for a Boiler Feed Pump

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Abstract

Proposed in this paper is a prediction model to estimate the suction flowrate of a boiler feed pump. The prediction model is developed by using the multiple regression technique, and consists of a response variable (Suction flowrate) and eight candidates of predictor variables (Discharge pressure, Discharge temperature, Suction pressure, BP suction pressure, Suction temperature, Speed reference, Speed, and Main steam pressure). For an accurate multiple regression equation, it is necessary to evaluate the relative importance of a predictor variable in a regression equation, which is determined by the proportion of the variance in the response variable accounted for by the predictor variable. Three different methods (Product measure, General dominance index, and Relative weight) have been applied to identify major predictor variables, and we develop multiple regression models by using identified major predictor variables.

Keywords: Prediction model, Suction flowrate, Boiler feed pump, Multiple regression equation

INTRODUCTION

A power plant is an industrial facility for the generation of electric power, and most of power plants contain multiple generators. A generator is a rotating machine that converts mechanical power into electrical power. By burning fossil fuels (such as coal, oil, and natural gas), a power plant makes the mechanical energy first, and then the generator converts the mechanical power into electrical power. A boiler feed pump, as shown in Figure 1, is a specific type of pump used to pump feedwater into the steam boiler of a power plant.

Figure 1. Boiler feed pump

The key performance indicator of a boiler feed pump is the suction flowrate, and the flow diagram is shown in Figure 2. The flow diagram includes 9 different physical parameters; A) Discharge pressure (bar), B) Discharge temperature (℃), C) Suction pressure (bar), D) BP suction pressure (bar), E) Suction temperature (℃), G) Speed reference (rpm), H) Speed (rpm), I) Main steam pressure (bar), and F) Suction flowrate (m^3/h). Although, the theoretical relationship among these parameters can be described by mathematical equations, it is not suitable for a boiler feed pump which has been used for a long time and has been degraded. For a degraded pump, it is important to predict the key performance indicator, 'suction flowrate'. Although, there have been many previous research results [6, 14, 15] on the performance prediction of a boiler feed pump, most of them belongs to the numerical simulation approaches and they are not suitable for degraded pumps.

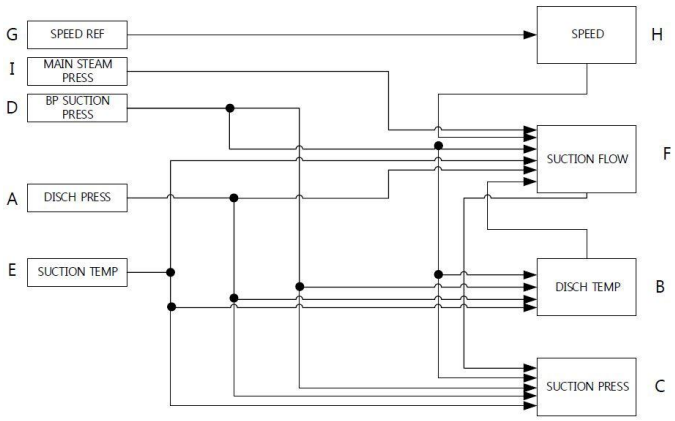

Figure 2. Flow diagram of a boiler feed pump

Multiple regression [1-5, 6-13] is a statistical technique that predicts values of one variable (dependent or response variable) on the basis of two or more other variables (independent or predictor variables). In the case of the boiler feed pump, the suction flowrate becomes the response variable and the remaining 8 parameters become predictor variables.

The objective of this paper is to propose a multiple regression approach to estimate the suction flowrate of a degraded boiler feed pump. The overall structure of this paper is as follows. Section 2 addresses the overall approach to the suction flowrate of a boiler feed pump, and Section 3 provides a detailed

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description of the proposed multiple regression methodology. Finally, some concluding remarks are provided in Section 4.

APPROACH TO SUCTION FLOWRATE ESTIMATION

In this paper, we use a multiple regression approach to estimate the key performance indicator of a boiler feed pump. As mentioned earlier, the suction flowrate becomes the response variable (**Y**) and the remaining 8 parameters become the predictor variables ($\mathbf{X_i}$, $1 \leq i \leq 8$). A successful multiple regression model should be able to provide accurate prediction results on the response variable for given predictor variables. To do so, it is necessary to identify important variables with better explanatory power than other predictor variables. Relative importance of a predictor (X_i) in a regression equation is determined by the proportion of the variance in the response variable (Y) accounted for by X_i.

A	B	C	D	E	F	G	H	I
DISCH	BFPT-A	BFPT-A	SUC	BFPT-A	BFPT-A	BFPT-A E	BFPT-A	BFPT-A	MAIN S
35F	35FV	35FP XA		35D	35D	35DW	35AT	35[	35M
196.3	155	11.390773		5.782	148.7	478.622	44.97	4190	166.6
196.2	155.1	11.399606		5.8	148.8	480.53	45.09	4191	166.2
197.6	155.1	11.464576		5.812	148.8	481.702	45.59	4208	168
197.9	155.1	11.439032		5.788	148.7	481.178	45.69	4209	168.1
198.2	155	11.458511		5.802	148.7	481.33	45.79	4214	168.6
198.1	155.1	11.462204		5.796	148.7	480.927	45.65	4213	168.6
197.4	155	11.416601		5.784	148.7	479.825	45.43	4204	167.8
196.1	154.9	11.381515		5.761	148.5	478.484	45.07	4191	166.4
196	154.8	11.376178		5.782	148.5	478.078	45.02	4188	166.4
197.7	154.9	11.420839		5.783	148.6	478.617	45.55	4204	168.2
198	155	11.434805		5.782	148.7	478.884	45.57	4208	168.7
197.3	154.9	11.416202		5.796	148.7	478.187	45.39	4200	168.3
196.7	154.9	11.392049		5.776	148.6	475.463	45.12	4194	167.6
197	154.8	11.384654		5.778	148.5	476.159	45.18	4195	167.8
197	154.9	11.407581		5.798	148.6	476.786	45.33	4195	167.6
197.5	154.9	11.41875		5.79	148.6	474.019	45.28	4200	168.7
196.5	155	11.403707		5.803	148.7	475.71	45.13	4192	167.4
196.7	154.9	11.407271		5.795	148.6	474.396	44.99	4192	167.7
196.1	154.9	11.393148		5.795	148.7	474.462	44.82	4186	167.1
195.4	155	11.35892		5.796	148.7	474.807	44.87	4181	166.4
197	155	11.408231		5.802	148.6	472.793	45.2	4194	168.2
196.3	155	11.411344		5.81	148.7	474.918	44.98	4188	167.5
196.8	155	11.398161		5.78	148.7	473.14	45.08	4193	168.4
196	154.9	11.381704		5.796	148.7	473.067	44.73	4184	167.5

Figure 3. Collected data from the simulation model of the boiler feed pump

For the determination of the relative importance of the predictors, there have been three major approaches; 1) 'Product measure approach' [13] based on the Pratt index of a predictor (Xi) which is the proportion of variable R^2 in the response variable (Y) accounted for by the predictor variable (Xi), 2) 'General dominance index approach' [2] based on the dominance which is a qualitative relation defined in a pairwise fashion (One variable is said to dominate another if it is more useful than its competitor in all subset regression), and 3) 'Relative weight approach' [9] based on the relative weight which is the proportionate contribution each predictor makes to R2, considering both its unique contribution and its contribution when combined with other variables.

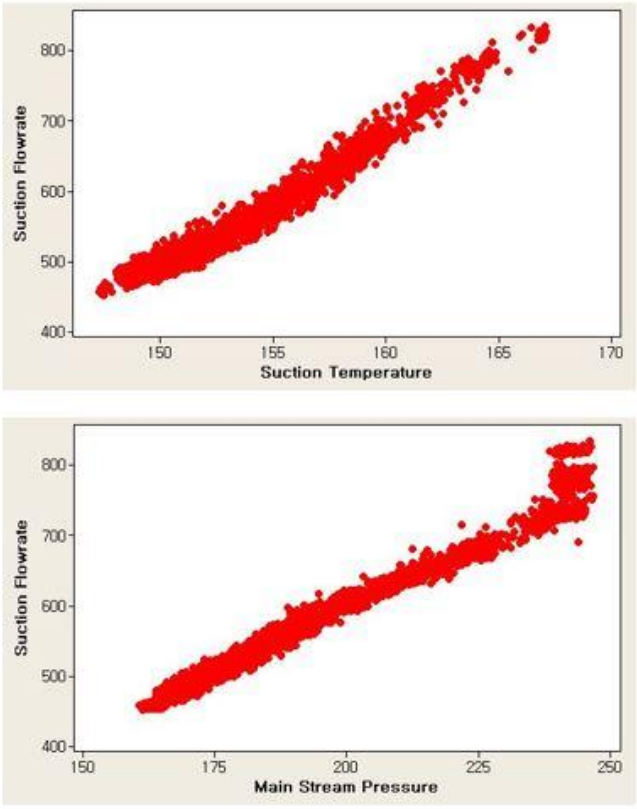

Figure 4. Graphs of suction flowrate and predictors

As, shown in Figure 2, the flow diagram includes 9 different physical parameters, the collected data is shown in Figure 3. The data has been generated by using the simulation model of the boiler feed pump, and consists of 70,000 rows. Figure 4 shows two example graphs of suction flowrate and predictors (suction temperature & main steam pressure).

MULTIPLE REGRESSION TO ESTIMATE SUCTION FLOWRATE

First of all, it is necessary to define the performance measure of a multiple regression model. We have 70,000 rows of observed data. Among the data, 50,000 rows are used for the construction of a multiple regression model, and 20,000 rows are used for the validation of the constructed multiple regression model. Accuracy of a multiple regression model is defined as the correct hit ratio. Correct answer of a regression model means that the answer should be within 1% range of correct answer. For example, the observed data is 100.0, then correct answer of a regression model should be within 1% range of the observed data (99.0~101.0).

As mentioned earlier, it is very important to evaluate the relative importance of a predictor variable (X_i) in a regression equation, which is determined by the proportion of the variance

in the response variable (Y) accounted for by X_i. In the case of the boiler feed pump, the suction flowrate becomes the response variable and the remaining 8 parameters are candidates for predictor variables. Among the 8 candidate variables, we want to determine 4 major predictor variables to build a multiple regression model.

Table 1. Selected four major predictor variables

	Selected four major predictor variables
Product measure approach	Suction pressure, BP suction pressure, Speed reference, Speed
General dominance index approach	Discharge pressure, Speed reference, Speed, Main steam pressure
Relative weight approach	Discharge pressure, Suction pressure, Speed reference, Main steam pressure

The three approaches (product measure, general dominance index, and relative weight) have been applied to determine the four major predictor variables (Table 1). The product measure, using the Pratt index of a predictor, chooses suction pressure, BP suction pressure, speed reference, and speed. The general dominance index chooses discharge pressure, speed reference, speed, and main steam pressure. Finally the relative weight approach chooses discharge pressure, suction pressure, speed reference, and main steam pressure. While the general dominance index and the relative weight choose quite similar predictors, the choice of product measure approach is different from the others.

Table 2. Multiple regression equations & Accuracies

	Regression equations	Accuracy
Product measure	Suction Flowrate = 426 - 146 Suction Pressure + 153 BP Suction Pressure + 18.1 Speed Ref + 0.00352 Speed	83.22%
General dominance index	Suction Flowrate = - 388 - 6.35 Discharge Pressure + 13.3 Speed Ref + 0.372 Speed - 0.299 Main Stream Pressure	97.16%
Relative weight	Suction Flowrate = - 376 - 6.93 Discharge Pressure - 2.86 Suction Pressure + 14.3 Speed Ref + 0.381 Speed	95.49%

By using the selected predictors, three multiple regression models have been constructed, as shown in Table 2. In terms of the prediction accuracy, the general dominance index shows the best result (97.16%). The relative weight approach shows similar level of accuracy (95.49%), because major predictors are similar. In the case of the product measure approach, the accuracy (83.22%) is not satisfactory compared to others. This is because the product measure approach is not suitable for predictor variables having multicollinearity relations.

DISCUSSION AND CONCLUSIONS

A boiler feed pump is a specific type of pump used to pump feedwater into the steam boiler of a power plant. The flow diagram of a boiler feed pump includes 9 different physical parameters (Discharge pressure, Discharge temperature, Suction pressure, BP suction pressure, Suction temperature, Speed reference, Speed, Main steam pressure, and Suction flowrate). For a degraded pump, it is important to predict the key performance indicator, 'suction flowrate'. To estimate the suction flowrate of a boiler feed pump, a prediction model is proposed in this paper.

The proposed prediction model is developed by using a multiple regression technique. To improve the accuracy of a multiple regression equation, it is necessary to identify important variables with better explanatory power than other predictor variables. For the determination of the relative importance of the predictors, there have been three major approaches (Product measure, General dominance index, and Relative weight). We develop three multiple regression equations by employing the three different approaches, and perform comparison between them. In terms of the prediction accuracy, the general dominance index shows the best result (97.16%). The relative weight approach shows similar level of accuracy (95.49%), because major predictors are similar. In the case of the product measure approach, the accuracy (83.22%) is not satisfactory compared to others. The major reason is that the product measure approach has weaknesses for predictor variables having multicollinearity relations.

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