Optimization of Matching on Torque Converter with Engine Based on Improved Radar Chart Method

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***Abstract*—In order to comprehensively evaluate the performance of matching between engine and torque converter, a series of matching evaluation indexes were developed according to the ideal matching principle and a standardized treatment for every index was put forward. Considering the different importance of each indexes in different applications, weight of each index was given by using comprehensive method, The evaluation method of the hydraulic torque converter and engine matching was established based on the improved radar map method. The objective function was constructed based on the sum of each evaluation index and the perimeter of radar map. With a hydraulic torque converter of ZL50 loader as an example, the effective diameter of circular circle on hydraulic torque converter was optimized in view of the shovel loading cycle condition. The original size of torque converter effective diameter was 0.340 m. After optimization, the effective diameter of hydraulic torque converter was 0.350 m, and the matching performance of engine and torque converter was increased by 7.4%. The results show that the optimal matching scheme can be improved by using the improved radar map method.**

Keywords-Torque converter; Matching; Improved radar chart method; Optimization; Wheel loader

I. INTRODUCTION

Hydraulic torque converter as a kind of hydraulic transmission device works with the engine in the course of work. After the matching of hydraulic torque converter and engine, it can be considered as a new power installation and its performance greatly depends on whether the matching of them is reasonable. Thus, it is necessary to make a comprehensive evaluation for the performance of the joint work [1, 2].

Aiming at the deficiency existing in the matching evaluation method of engine and hydraulic torque converter, this paper makes a further improvement on the traditional radar chart [3, 4]. Through the formulation of dimensionless matching evaluation index and the empowerment by principal component analysis, this paper establishes the comprehensive evaluation method of the matching of a hydraulic torque converter and engine. Based on it, the objective function is constructed. And aiming at shovel mucking drive cycle, the diameter of the effective circulating circle of the hydraulic torque converter of ZL50 loader is optimized.

II. EVALUATION INDEX OF MATCHING PERFORMANCE

According to the matching principle of hydraulic torque converter and engine, this paper selects five evaluation indexes of matching performance and standardizes each index, which is shown in table I [5, 6].

TABLE I. EVALUATION INDEXES OF MATCHING PERFORMANCE

Evaluation indexes	Formula
Maximum torque output coefficient a_1	$T_1/T_{\max}$
Maximum power output coefficient a_2	$P_1/(P_{eH}\eta_{\max})$
Width of the efficient workspace a_3	$(n_{w2}-n_{w1})/n_{\max}$
Power output coefficient a_4	$\bar{P}_1/(P_{eH}\bar{\eta})$
Coefficient of fuel consumption a_5	$(g_{\max}-\bar{g}_e)/(g_{\max}-g_{\min})$

In the table I: T_1 refers to the crossover point torque between load parabola and engine's net torque curve when the transmission ratio of hydraulic torque converter $i=0$; $T_{\max}$ refers to the maximum net output torque of engine; P_{eH} refers to the maximum net output power of engine; $\eta_{\max}$ refers to the peak efficiency of the hydraulic torque converter; P_1 refers to the maximum output power of the hydraulic torque converter; n_{w1} and n_{w2} refer to the corresponding turbine speed when the efficiency of the hydraulic torque converter η_1 is equal to 0.75; $n_{\max}$ refers to the maximum output speed of turbine shaft; $\bar{\eta}$ refers to the average efficiency of the hydraulic torque converter when η_1 is greater than or equal to 0.75; $\bar{P}_1$ refers to the average output power of the turbine shaft of hydraulic torque converter when η_1 is greater than or equal to 0.75; $\bar{g}_e$ refers to the average effective fuel consumption rate; g_{max} refers to the maximum fuel consumption rate of engine; g_{min} refers to the minimum fuel consumption rate of engine.

According to the definition of each formula in table I, the greater the value of each evaluation index, the better the matching performance of the corresponding engine and hydraulic torque converter. Because of the different importance of each evaluation index, the evaluation index should be weighted. This paper uses principal component analysis to empower each index [7, 8].

III. CONSTRUCTION OF EVALUATION FUNCTION BASED ON THE IMPROVED RADAR CHART

A. Drawing of Improved Radar Map

This paper perfect the traditional radar chart further. The construction method is as follows [9, 10]:

1) The standardized evaluation index is weighted. The weight is sorted from large to small and the obtained weight after sorting is q_1, q_2, q_3, q_4, q_5, each index value is sorted anew according to the corresponding order, which is e_1, e_2, e_3, e_4, e_5. According to the weight, the corresponding sector angle $\theta_j = 2q_j\pi$ of e_j index in radar chart can be obtained.

2) Determine the index shaft. Firstly, we should draw a unit circle. And then we should draw a horizontal ray from the center of the circle O. The ray and circle intersect at point A. Then we should draw rays OB, OC, OD, and OE in order under ray OA, and then draw diagonals of sectors AOB, AOC, BOD, COE, and DOE. The diagonals and circle intersect at points M1, M2… M5. Lines OM1, OM2… OM5 are taken as the index shaft.

3) we should mark e_1, e_2, e_3, e_4, e_5 in the index shaft according to the length and then the points A', B', C', D', E' can be obtained in order. Finally we should connect point A'-B'-C'-D'-E'. The improved radar chart with comprehensive evaluation can be obtained, which is shown in Fig. 1.

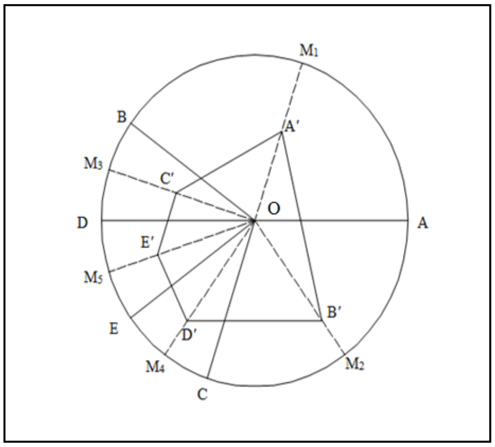


Figure 1. Improved radar map

B. Construction of Objective Function

According to the construction method of radar chart, the better the matching performance of the engine and hydraulic torque converter, the larger the perimeter of pentagon ABDEC. Based on the perimeter of pentagon, the optimization function is constructed:

$$\begin{cases} f(D) = \sum_{k=1}^{5} \alpha_k C_k \\ C_k = l_{A'B'} + l_{A'C'} + l_{B'D'} + l_{C'E'} + l_{D'E'} + \sum_{j=1}^{5} q_j e_j \\ L_{A'B'} = \sqrt{e_1^{\ 2} + e_2^{\ 2} - 2e_1e_2 \cos\frac{\theta_1+\theta_2}{2}} \\ L_{A'C'} = \sqrt{e_1^{\ 2} + e_3^{\ 2} - 2e_1e_3 \cos\frac{\theta_1+\theta_3}{2}} \\ L_{B'D'} = \sqrt{e_2^{\ 2} + e_4^{\ 2} - 2e_2e_4 \cos\frac{\theta_2+\theta_4}{2}} \\ L_{C'E'} = \sqrt{e_3^{\ 2} + e_5^{\ 2} - 2e_3e_5 \cos\frac{\theta_3+\theta_5}{2}} \\ L_{D'E'} = \sqrt{e_4^{\ 2} + e_5^{\ 2} - 2e_4e_5 \cos\frac{\theta_4+\theta_5}{2}} \end{cases} \quad (1)$$

In the Equation (1): α_k is the weight of each working period, which is determined by the job time allocation. C_k is the sum of the perimeter of matching radar chart and each evaluation index of each working period. $l_{A'B'}$, $l_{A'C'}$, $l_{B'D'}$, $l_{C'E'}$, and $l_{D'E'}$ are the length of each side of the pentagon.

C. Program Design

The effective circular circle diameter of hydraulic torque converter is taken as the optimization variable to optimize the matching performance of the engine and hydraulic torque converter. Using MATLAB to prepare the calculation program, the calculation of the block diagram shown in Fig. 2.

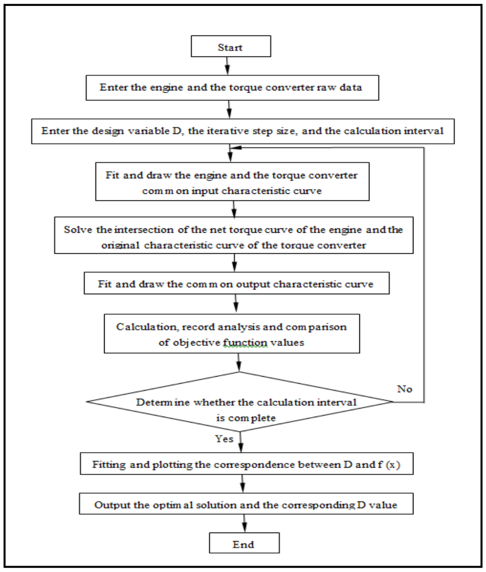
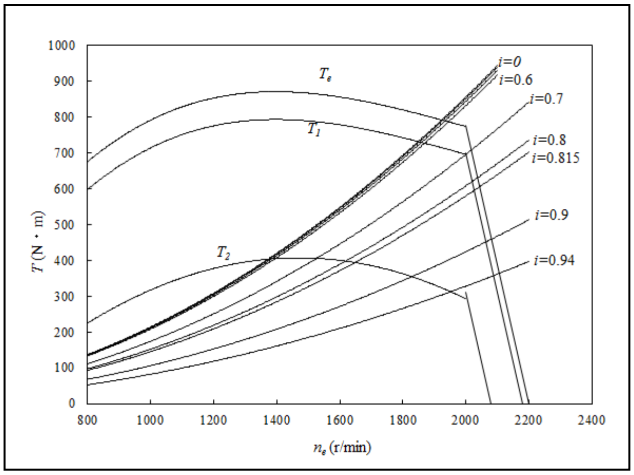


Figure 2. Figure 2. Program flowchart of matching evaluation

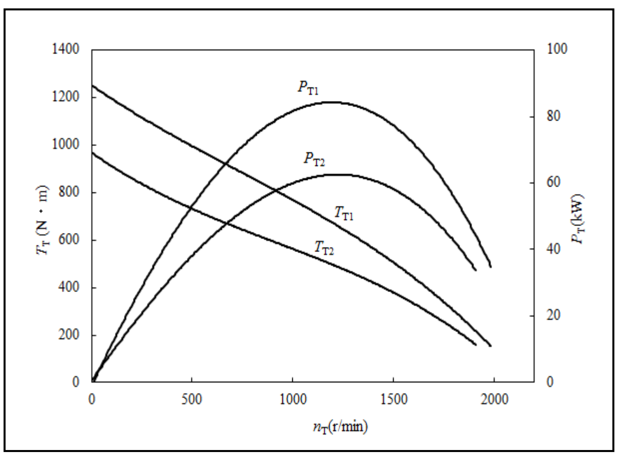
IV. Optimization Analysis

In this paper, the torque converter of ZL50 loader is taken as an example to optimize the matching performance of I shovel cycle.

1) According to the net output torque of the engine and the original data of hydraulic torque converter of each working period, the common work input and output characteristics of the engine and hydraulic torque converter are calculated [11,12].



a. Input characteristics



b. Output characteristics

Figure 3. Characteristics of engine working together with torque converter

2) Evaluation indexes of each working period are calculated respectively.

3) The above steps should be repeated, and then the evaluation index value of different diameters D should be calculated respectively.

4) The weight of matching evaluation index is determined. The evaluation matrix is constructed by obtained matching scheme by diameters of different circular circles:

$$\boldsymbol{U}=\begin{bmatrix} 0.837 & 0.919 & 0.519 & 0.786 & 0.570 \\ 0.879 & 0.944 & 0.525 & 0.815 & 0.609 \\ 0.918 & 0.975 & 0.530 & 0.842 & 0.627 \\ 0.932 & 0.987 & 0.539 & 0.853 & 0.661 \\ 0.937 & 0.984 & 0.549 & 0.878 & 0.697 \\ 0.940 & 0.988 & 0.560 & 0.876 & 0.729 \\ 0.950 & 0.980 & 0.569 & 0.899 & 0.741 \\ 0.959 & 0.978 & 0.579 & 0.905 & 0.749 \\ 0.963 & 0.973 & 0.589 & 0.904 & 0.744 \\ 0.961 & 0.966 & 0.600 & 0.896 & 0.737 \\ 0.941 & 0.960 & 0.610 & 0.883 & 0.745 \\ 0.922 & 0.955 & 0.622 & 0.869 & 0.749 \\ 0.890 & 0.980 & 0.631 & 0.888 & 0.735 \\ 0.848 & 0.935 & 0.650 & 0.833 & 0.699 \end{bmatrix} \quad (2)$$

In the Equation (2): $u_{rj}=\sum_{k=1}^{5}\alpha_k a_{jk}$, a_{jk} is the a_j index of each working period. The weight vector of principal component analysis can be obtained through the calculation:

$$W=[0.238, 0.203, 0.114, 0.236, 0.209] \quad (3)$$

5) According to the formula (1), the corresponding objective function values of diameter of different circular circles are calculated. The results are shown in Fig. 4.

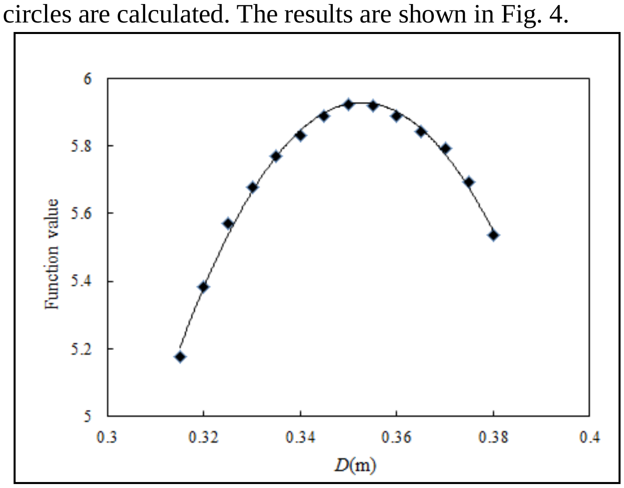


Figure 4. Corresponding relationship of D Values with objective function values

According to the Fig. 4 we can see that when D =0.350m, the matching performance of hydraulic torque converter and engine is optimal.

TABLE II. CALCULATION VALUES OF EVALUATION INDICATORS BEFORE AND AFTER OPTIMIZATION

Evaluation indexes	Before optimization	After optimization	Increased proportion (%)
A_{11}	0.902	0.935	33.7
A_{12}	0.982	0.985	16.7
A_{13}	0.51	0.54	6.1
A_{14}	0.82	0.886	36.7
A_{15}	0.579	0.667	20.9
A_{21}	0.982	0.997	83.3
A_{22}	0.975	0.967	-32
A_{23}	0.611	0.641	7.7
A_{24}	0.922	0.934	15.4
A_{25}	0.884	0.879	-4.3

According to the table II, we can see that after optimization, the matching performance of all is improved to some extent except a_2. In the optimization process, the gap between the function value and the ideal value is decreased gradually. We can use the following formula to calculate the degree of improvement of matching performance before and after the optimization:

$$y = \frac{f' - f}{f^{\max} - f} \tag{4}$$

In the Equation (4): f and f' are the function values before and after the optimization respectively; $f^{\max}$ is the ideal value. By using the upper calculation, after the optimization, the overall matching performance is increased by 7.4%. The performance evaluation radar map for the performance evaluation of the engine and the hydraulic torque converter is shown in Fig. 5.

V. ACKNOWLEDGMENT

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VI. CONCLUSION

This paper utilizes the improved radar chart method to optimize the matching performance of hydraulic torque converter and engine and links up the interaction of multiple dimensionless evaluation indexes. The angle of each sector also embodies the importance of different indexes and avoids the irrationality of equal distribution. After the optimization, the overall matching performance can be increased by 7.4%. The results show that it is effective and feasible to adopt the improved radar chart method to evaluate and optimize the matching performance of hydraulic torque converter and engine and also it can provide the reference for the selection of matching schemes.

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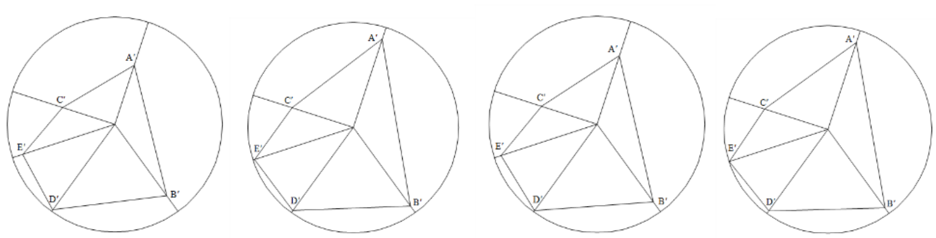

Figure 5. The radar map of engine and torque converter matching performance evaluation of before and after optimization