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Review

Evaluating wheel loader operating conditions based on radar chart☆

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ABSTRACT

The evaluation of the difficulty level of operating conditions is one of the key problems in intelligent management of the wheel loader engine power. This paper presents a method for evaluating the difficulty level of wheel loader operating conditions based on radar chart. Firstly, we analyze the characteristics of the wheel loader operation spectrum, and determine the boom head cylinder pressure as the analysis object. Then, based on the analysis object we establish the characteristic indexes that can express the operating conditions and determine eigenvalues of the characteristic indexes with clustering analysis algorithms. Lastly, we draw the eigenvalues on the radar chart, and extract the area enclosed by the eigenvalues to compare with the area of the radar chart. The ratio of enclosed area of radar chart is defined as the difficulty level of operating conditions. This method is validated under various industrial conditions (i.e. four types of operating conditions, three power modes and three drivers manipulating the wheel loader). The results indicate that the proposed method to evaluate the difficulty level can accurately quantify the real operating conditions, and is a useful tool for management of engine power modes according to the quantified operating conditions.

1. Introduction

As energy shortages and environmental pollution have become grave concerns, development of a green economy [1–2] with high energy efficiency becomes a topic of great interest. Europe, the United States and other developed countries and regions have considered energy saving indexes as mandatory provisions of product license for wheel loaders. China has also enacted mandatory regulations on wheel loader emissions standards. Wheel loader energy saving is one of the most important goals for engineering machinery enterprises and scientific research institutions. A large number of research project [3–11] about energy saving strategies for wheel loaders have been conducted, and received many excellent achievements. Improvements in transmission system efficiency through wheel loader transmission shift strategy optimization [6–9] and engine multi-power mode control [10–12] are important research goals for current researches on wheel loader energy saving.

Due to harsh working environments and complex operating conditions of loaders, and in order to improve the adaptability to variable loads, researchers at home and abroad have adopted various shift strategies [6–9] to improve wheel loader adaptability and operation efficiency for energy-saving. Operating conditions are the indexes by which operational difficulty levels can be measured. Such conditions have become an important part that needs to be considered for the optimization of wheel loader shift strategy. Unfortunately, operating conditions have not been applied to the optimization of shift strategies due to the lack of specific methods to evaluate their difficulty level.

There are multi-power modes for wheel loaders, usually the economy, standard and high power modes (or only economy and high power modes). Each mode has its own external characteristic curve and speed regulation characteristic curve. The power mode can be switch either manually or automatically. However, the model, in general, is switched manually due to the lack of difficulty level evaluation methods for operating conditions. Therefore, the evaluation of difficulty level of operating conditions is one of the key problems in intelligent adjustment of wheel loader engine power.

Radar chart is one of the widely methods for comprehensive evaluation [13–15]. The most distinct characteristic of radar chart is its intuitive visualization, by which the status of to-be-evaluated object can be displayed intuitively. Therefore, this paper selects the radar chart to make a qualitative evaluation; meanwhile, it can achieve a quantitative evaluation via combination of numerical proportions.

In summary, the identification of operating conditions is of great significance for investigating wheel loader energy efficiency, and this

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paper presents a method for evaluating the difficulty level of wheel loader operating conditions based on radar chart. Firstly, we analyze the characteristics of the wheel loader operation spectrum, and determine the boom head cylinder pressure as the analysis object. Secondly, based on the analysis object, the characteristic indexes are found, which can express the operating conditions and determine eigenvalues of the characteristic indexes with clustering analysis algorithms. Lastly, the eigenvalues are drawn on the radar chart, and the area enclosed by the eigenvalues are compared with the area of the radar chart. The ratio of the two areas is the difficulty level of operating conditions. This method is verified under four different operating conditions, three different drivers, and three different power modes. The analysis results agree with the value of the difficulty level under real operating conditions.

2. Evaluation method of operating conditions

2.1. Analysis of eigenvalues of operating conditions

In order to evaluate the difficulty level of operating conditions of the wheel loader, the operation spectrum acquisition focuses on four kinds of material objects, namely fine sand, coal cinder, iron ore and native soil, and the operation spectrum obtained from the acquisition is extracted by the work cycle, and is segmented by the operation. After analysis, the change of the pressure at the boom head cylinder of the mining section is selected as the basis for evaluation of operating conditions. Fig. 1 shows the curve of boom head cylinder pressure of mining section under four operating conditions, which is obtained through operation segmentation. The following conclusions can be drawn according to this curve:

(1) Different materials result in different time length of each mining operation and different change rates of mining operation time due to their different conditions and densities. Comparison between the fine sand and iron ore implies that both are in dispersed granular state. Because the iron ore features high density, large volume and greater excavation difficulty, it takes more time for mining operation and the change rate of mining time length is extensive.
(2) Different materials result in different maximum pressure values of boom head cylinder, and different change rates of the maximum pressure during single mining operation due to their different states and densities. Comparison of fine sand and iron ore finds that the density of iron ore is larger than that of fine sand, and so the maximum pressure values of the boom head cylinder. However, the change of the maximum pressure of the former is relatively slower than the latter.

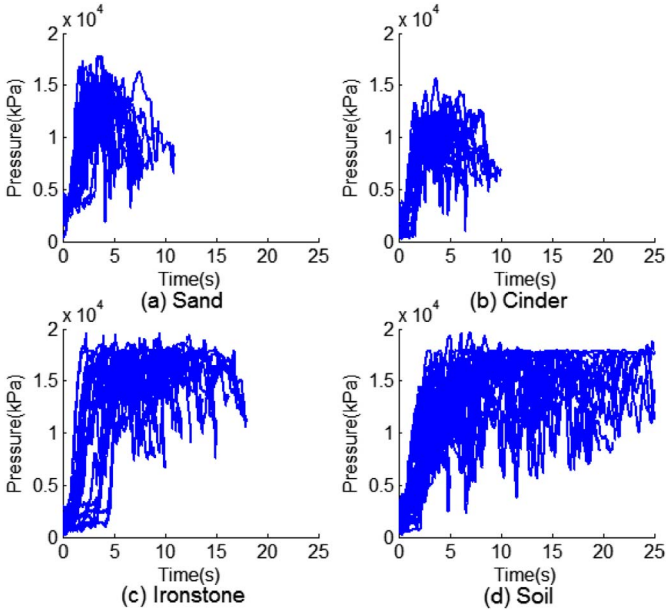

Fig. 1. The curve of boom head cylinder pressure of wheel loader's mining section under four operating conditions.

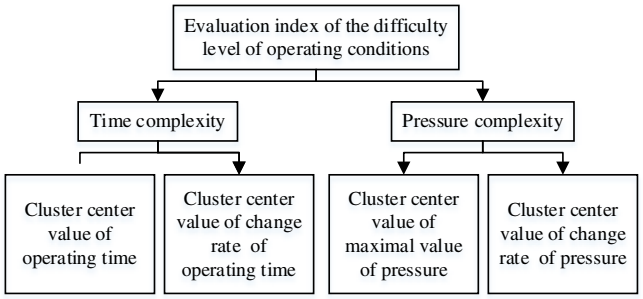

Fig. 2. Evaluation index of operating conditions.

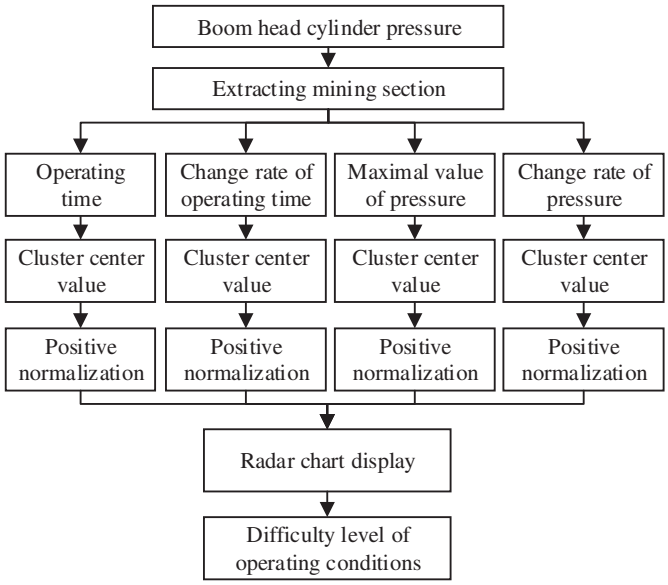

Fig. 3. Evaluation method of operating conditions.

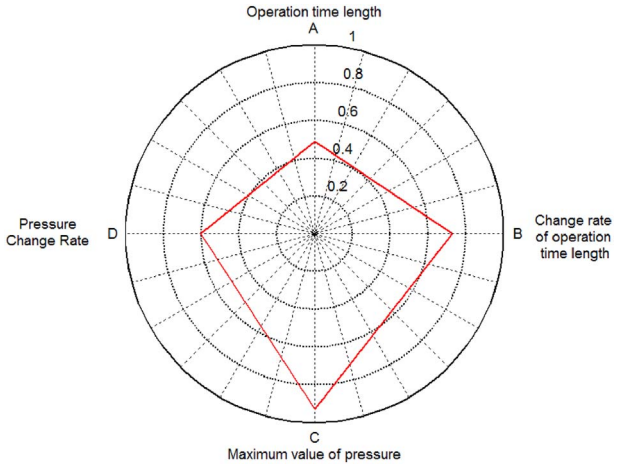

Fig. 4. The characteristic values on the radar chart.

According to the above analysis, the evaluation of the difficulty level of operating conditions should be a multi-sample, comprehensive