Assessment of piston quality using QFD-analysis

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Abstract. The article examines the state and prospects of agricultural machinery in the Russian Federation, studies of the parameters of accuracy and quality of ZMZ engine pistons using QFD analysis. As a result of the construction of the "House of Quality" for the use of the ZMZ engine piston at repair enterprises, it is necessary to carry out the following measures: enhanced control of piston markings; advanced training of workers who process the piston surface; improved control over the mass of manufactured pistons.

1 Introduction

The economic well-being of each country is integrally linked to the development of agriculture. At the moment, the Russian Government is actively supporting the development of this industry. New farms are being created, engaged in crop production, livestock breeding and fishing. To develop these areas, it is necessary to provide farms with vehicles, as well as the organization and conduct of processes at all stages.

Currently, the production of agricultural machinery in our country is actively declining. As a result, all work is not completed on time, which leads to significant product losses.

The analysis showed that in the structure of the equipment fleet there is an increase in equipment with a service life of more than ten years. This technique has the highest probability of failure.

But in addition to tractors and combines, road transport plays a significant role in agriculture, occupying about 3% of all agricultural machinery. Vehicles used in this sector must have special qualities, such as mobility, high productivity, the ability to deliver goods without transshipment, and also perform transport and technical tasks.

Due to the lack of equipment, the importance of enterprises engaged in repair and maintenance increases. Timely and high-quality repairs are necessary to maintain the performance of equipment.

The failure rate of the cylinder-piston group (CPG) of engines is about 35%. Therefore, in order to reduce the number of failures, it is necessary to improve the quality of repairs of this group. Engine performance depends on the reliable operation of the cylinder-piston group.

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Over the entire period of use of domestic agricultural machinery, CPG parts are replaced several times. Agricultural producers suffer huge economic losses due to inadequate maintenance of domestic equipment. Costs for maintenance, spare parts and repairs amount to more than 60 billion rubles per year. Moreover, most cars are repaired every season. The need to ensure quality and reliability of agricultural machinery is the primary requirement of an agricultural producer.

When repairing internal combustion engines, some parts must be completely replaced with new ones. In this case, the repair company can choose both parts from the manufacturer and analogues manufactured at various enterprises. Many works indicate [1, 2] that the quality of production at the manufacturing plant is, as a rule, higher than that of factories producing analogues. The quality of parts is assessed according to several parameters, such as geometric dimensions, weight [3], shape and position of surfaces [4, 5]. When monitoring the quality of parts, special attention is paid to those surfaces that form the fit, since the durability of the unit as a whole depends on ensuring the accuracy of the fit [6, 7]. The quality of operation of the assembly unit is ensured by compliance with the required standards of accuracy, strength and reliability [8 - 10].

The purpose of the work is to study the parameters of accuracy and quality of pistons of the ZMZ-402 engine using QFD analysis.

2 Research materials and methods

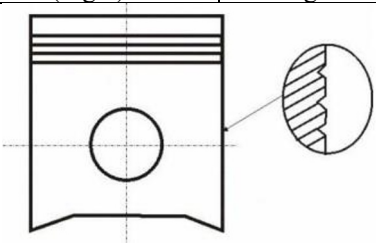
QFD is a systematic method of shaping consumer needs and desires by creating the tasks and functions of a company's activities. As a result, the final result must meet consumer expectations at each stage of product creation. A manufacturer who wants to create an "imagined" quality that meets consumer expectations must first have a clear understanding of the "quality profile" of the product he is trying to create.

3 Results

Due to the fact that the quality of the piston is of great importance for the correct operation of the engine, the technical data of the manufacturer of similar pistons was analyzed. The research data are shown in Table 1.

Results of a study of products from an alternative manufacturer and the consequences of using parts with deviations from the design documentation of the ZMZ-402 engine piston.

Table 1. Competitive manufacturer analysis

Parameter deviation	Consequences
Exceeding the vertical profile of the piston diameter by 0.002 - 0.011 mm. (Fig.1)	Increased oil consumption, loss of power and engine knocking
 Fig.1	
The perpendicularity of the forming end surfaces of the grooves (for piston rings) to the	Increased oil consumption (Fig.3)

piston skirt axis is not observed (Fig. 2). Deviation from tolerance exceeds the permissible value by 0.006 mm	

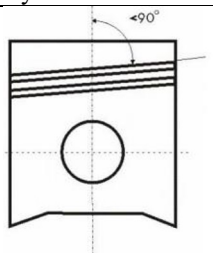


Fig. 2

Fig. 3

Exceeding the tolerance for displacement of the piston pin axis relative to the piston bottom by 0.02 mm (Fig.4)	Detonation, overheating, scuffing and engine seizure

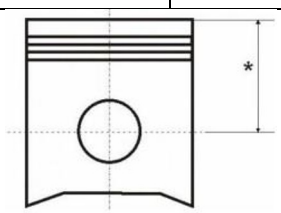


Fig.4

Exceeding the piston mass tolerance (tolerance +/- 2 grams)	Engine vibration, operating noise and the occurrence of high voltages at high speeds, which leads to engine destruction
Deviation from the cylindricity of the piston pin hole by 0.0025 mm (Fig.5)	Knocks in the engine, destruction of the piston and jamming of the engine (Fig.6)

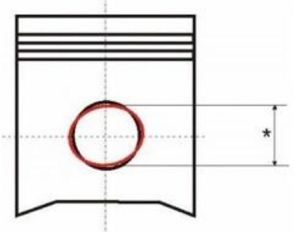


Fig.5

Fig.6

Inconsistency with the chemical composition	Piston scuffing, burnout and destruction
There are no oil passages to lubricate the piston pin (Fig.7)	Increased wear, pin jamming and connecting rod head breakage

Fig. 7

The data obtained indicate that the use of parts with deviations from the ZMZ design documentation leads to numerous problems in the operation of the engine and even to its breakdown. Therefore, it is necessary to use only parts from the original manufacturer.

QFD analysis of ZMZ engine piston.

QFD is a systematic method of shaping consumer needs and desires by creating the tasks and functions of a company's activities. As a result, the final result must meet consumer expectations at each stage of product creation. A manufacturer who wants to create an "imagined" quality that meets consumer expectations must first have a clear understanding of the "quality profile" of the product he is trying to create. The following are the stages of creating a "House of Quality":

1st stage. Defining consumer expectations

The first step is to identify a specific consumer group and identify characteristics that will meet consumer expectations.

The list of consumer expectations was compiled based on an analysis of oral surveys and taking into account the opinions of experts in the field of marketing, production and sales of relevant products. At this step, the following requirements were identified: low fuel consumption, no scuffing, no knocking in the engine, power, low oil consumption, no engine overheating, low engine vibration, indestructible piston and indestructible engine.

Since all these expectations are equally important to consumers, they are rated on a five-point scale as follows:

5 – extraordinary value;

4 – good value;

3 – average value, worth keeping in mind;

2 – low value;

1 – is of no value.

For example, low oil consumption expectation received a score of four, while power expectation received a score of five.

2nd stage. Determining the comparative value of products

At this step, the studied ZMZ engine piston is compared with a competitor's product. As a result, you can easily understand how high quality the original piston is compared to similar competitor products. Here again a five-point scale is used.

The results of this comparison are presented in table 2. It can be seen that the piston under study is ahead of the competitor's products in terms of fuel consumption, absence of scuffing, absence of knocking in the engine and absence of engine overheating. It has the same parameters for power, oil consumption, piston indestructibility and engine indestructibility. But competitors are ahead in engine vibration. All these data indicate potential opportunities for improvement of the original products.

3rd stage. Setting Project Goals

At this stage, it is necessary to improve (change) the level of existing indicators of satisfaction of consumer expectations in comparison with the indicators established for competition. In Table 2 sets target values (numerical indicators) for each consumer expectation. This is again a five-point scale.

For product expectations (characteristics) that do not require improvement, target values are set at the same level as the current score for that expectation. In this case, fuel consumption, engine knock prevention, oil consumption, overheating prevention and piston integrity are identified as characteristics that do not require improvement.

Based on the target values, the relative values of the "degree of improvement" in quality (for each product characteristic) were calculated using the following formula:

$$S.u. = \frac{C.z.}{O.p.} \qquad (1)$$

where: S.u. – degree of improvement, C.z. – target value, O.p. – product evaluation;

The results of calculations using formula 1 are given in Table 2, according to which it was decided to improve the following consumer expectations: no scuffing, power, low engine vibration, no engine destruction to a "degree of improvement" equal to 1.25 for each of these parameters.

Weighting coefficients for each consumer expectation (product characteristics) were calculated as part of defining the project goals and calculated using the formula:

$$\text{Weight.o.p.} = \text{Important.o.p.} \cdot \text{S.u.}, \quad (2)$$

where: Weight.o.p. – the weight of consumer expectations, Important.o.p. – the importance of consumer expectations, S.u. – degree of improvement.

The results of calculations using formula 2 are given in table 2. The bottom line of this column indicates the sum of all weight values (46.75). Taking this amount as 100%, the weight of each consumer's expectations is calculated as a percentage and is given in table. 2.

4th stage. Description of product technical characteristics

Once the steps of visualizing customer expectations and assessing their importance are completed, the problem of ensuring that those expectations are met must be addressed. In this case, it is determined which parameters (characteristics) of the product can be changed to meet consumer expectations. More precisely, it is determined how the technical characteristics of the product (what needs to be done?) relate to what consumers expect and want to receive (what needs to be done?).

The analysis revealed seven technical characteristics of the piston, which are given in Table 2, related to consumer expectations, namely: correct marking, roughness of the vertical profile of the piston skirt, perpendicularity of the forming end surfaces of the grooves, displacement of the piston axis pin relative to the piston bottom, piston mass, roughness of the piston pin holes and the chemical composition of the piston material.

It is the correct choice of these values that determines the success of designing a high-quality ZMZ engine piston.

5th stage. Filling out the connection matrix

At this step, the strength of the influence of product technical characteristics on the realization of consumer expectations was directly examined.

For this purpose, a matrix of connections was used, which is a common part of the "House of Quality".

Each element of the matrix, located at the intersection of its rows and columns, determines the existing strength of the relationship between consumer expectations and technical characteristics. Where such a connection exists, the symbol of each of these elements determines the strength of this connection.

When filling out the elements of the relationship matrix, the symbols given in Table 1 are used to indicate the strength of the relationship.

Table 2. Symbols and coefficients used to describe the strength of the relationship

Symbol	The power of connection	Weight coefficient
⊙	High	9
O	Average	3
Δ	Low	1

Numerical estimates of the importance of the connection between each technical characteristic of the piston are indicated in the cells of the connection matrix in the "House of Quality" section and are calculated using the formula:

$$Z.v. = S.v. \cdot B., \%, \quad (3)$$

where: Z.v. – significance of the relationship, S.v. – strength of relationship, V. – weightiness.

When calculating using formula (3), the numerical values of the weighting coefficients "Strength of Relationship" are used, and the values of the indicators "Weight, %" are taken according to the data in the fourth column "House of Quality".

The top line "Significance of the Relationship" of Table 2 shows the sum of the values of the "Total Score" indicator in each column and the priority of each technical characteristic in the piston.

All values in the Total Score line are added together. The bottom line gives the numerical priority of each technical characteristic in the piston.

When producing a ZMZ engine piston, special attention should be paid to the highest priority technical characteristics.

6th stage. Technical analysis

At this step, the top line of part presents the units of measurement for each technical characteristic of the product, for example, the characteristic "Piston mass" has units of measurement - grams.

Using these units of measurement, the technical specifications of the "Original" and Competing Products are summarized.

7th stage. Determining target values for product technical characteristics

In the final step, product technical performance targets are determined and prioritized based on available information. Target values are directly related to improving product performance. As a result, it becomes known what improvements need to be made. In this case, the following indicators are priority: "Correct marking", "Roughness of the vertical profile of the piston skirt" and "Piston mass".

Table 3. "Home of quality assessment of piston quality"

Specifications / Consumer Expectations	Importance	Correct labeling	Roughness of the vertical profile of the piston skirt	Perpendicularity of the forming end surfaces of the grooves	Displacement of the piston pin axis relative to the piston groups	Piston mass	Roughness of the piston pin hole	Chemical composition of the piston material	Grade					Target value	Degree of improvement	Weight	Weight, %
									1	2	3	4	5				
Minimum fuel consumption	5	⊙				Δ								5	1	5	11
No scoring	5	⊙	⊙		⊙			⊙						5	1, 25	6,25	13
No knocking in the engine	4	⊙	⊙					Δ						4	1	4	8, 5
Power	5	⊙	⊙											5	1, 25	6,25	13
Minimum oil	4		⊙	⊙			Δ							5	1	4	8, 5

consumption																	
No engine overheating	5				⊙									4	1	5	11
Low engine vibration	4					⊙								5	1,25	5	11
Piston indestructibility	5			⊙			⊙	⊙						5	1	5	11
Engine indestructibility	5					⊙								5	1,25	6,25	13
Total score		409,5	387	175,5	216	249	124,5	141,5								46,75	100
Priority		23	21	10	12	14	7	13									
Unit		%	mm	degree	mm	g	mm	%									
"Original" products		100	0,025	90	0,03	567	0,025	100									
Competitor's products		90	0,023	89	0,08	567	0,025	100									
Target value		100	0,025	90	0,01	567	0,025	100									

4 Conclusion

Recently, the market of spare parts for car repairs has been flooded with fakes. Due to the lack of a control mechanism, almost a quarter of automotive services have encountered counterfeit goods. Consumers are concerned that services are using low-quality parts.

As a result of the construction of the “House of Quality” for the production of ZMZ engine piston, the following activities must be carried out:

Enhanced control of piston markings; advanced training of workers who process the piston surface; improved control over the mass of manufactured pistons.

QFD analysis identifies the relevant customer, project and production requirements, including the factors and quality characteristics associated with each requirement. QFD begins “quality planning” and “quality design” early in the process and continues until the product is “introduced” into mass production. It plays a key role in determining the quality of the relationship between the finished product and each subsystem, which guarantees the reliability of the system.

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