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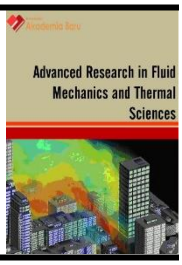

Remanufacturing Feasibility of Bike Suspension by Hybrid TOPSIS - Taguchi Optimization

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ABSTRACT

Remanufacturing is a need for the industry to overcome the scarcity of raw material. Although it is economical and creates less environmental impact, we need to have more strategies for the selection of components form scrap and improving the basic design of components thereby more scrap can be converted into remanufactured products. This paper focuses on the selection of bike suspensions for remanufacturing and also finds the influential parameters to improve the quality of scrap. For selection and identification, we taken bike suspensions of Honda twister from different regions and applied hybrid fuzzy TOPSIS and Taguchi optimization. Remanufacturing of used bike suspension will be effective since more than 50% of the used bike suspensions are selected for remanufacturing by Taguchi analysis. The study reveals that Seal internal diameter of bike suspension is the most influential parameter and the focus of Seal internal diameter design will increase the number of bike suspension selected for remanufacturing.

1. Introduction

Sustainability is the major concern for industry which leads to an economic and social growth of industry by reducing the environmental impact [1]. In most of the methods, Fuzzy assessment is carried to counter the uncertainty of the core quality [2]. To support the decision making in selection optimization algorithms are applied like multi-criteria decision making, Finite element analysis with a neural network, Analytical Hierarchy process, DEMATEL and Jacobian-Torsor model [3,4]. Here we are considering the used bike suspension as a case study for feasibility analysis for remanufacturing through Fuzzy TOPSIS and Taguchi Desirability analysis. To start with the analysis, we collected data of 4 Bike Suspensions of Honda twister 2012 model. The Bike Suspensions were completely

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dismantled. We collected Bike Suspensions from different regions. The parameters we considered are Cylinder height, piston OD, piston height, cylinder ID, Stiffness and Seal ID. Due to the unpredictability of the quality of the cores collected remanufacturing becomes a complex process to perform. As compared to the manufacturing skillset required in the remanufacturing is more. After collection of the core proper inspection is needed to find out dimensional changes of the product as well as subparts. Figure 1 and Figure 2 show the bike suspension parts and springs taken from different bike suspensions. The dimensions of the Bike Suspensions parts are shown in Table 1.

Fig. 1. Bike suspension parts

Fig. 2. Suspension springs taken from different suspensions

Table 1
Used Bike suspension parts dimensions

Parameters	Suspension 1	Suspension 2	Suspension 3	Suspension 4	Suspension 5
Piston OD	15.70666667	15.88666667	15.94333333	15.75333333	15.88333333
Piston Rod Height	153.0666667	154.58	153.4333333	153.2	153.1
Cylinder ID	11.67266667	11.79833333	11.66766667	11.78233333	11.83066667
Cylinder Height	186.2666667	186.22	186.6	186.7666667	183.5333333
Seal ID	3.892333333	3.837	3.890333333	3.913333333	3.856333333
Avg. stiffness		234750	240916.6667	247500	257833.3333
Weight		0.632	0.636	0.628	216.4
Free length		215.9666667	215.4333333	0.632	215.3

2. Fuzzy Topsis Analysis

Fuzzy refers to the situation whose set of activity boundaries are not well defined. TOPSIS is a widely adopted MCDM technique to solve multiple-criteria decision-making problems in various fields [5]. Fuzzy-TOPSIS is domain independent and thus may be applied virtually to any problem [6]. Several research groups have regularly used Fuzzy-TOPSIS or its variants in a wide range of problems. Fuzzy-TOPSIS analysis is carried out for critical component selection [7]. Linguistic variables R1, R2, R3, R4, R5, and R6 were assigned to influential parameters used to remanufacture the bike suspension like Cylinder height, piston OD, and piston height, cylinder ID, Stiffness and Seal ID. Similarly, P1, P2, P3, P4, P5, and P6 were assigned for the remanufacturing parameters like remanufacturing ability, quality, level of integration, cost saving, EOL condition, and durability. The linguistic variables and remanufacturing parameters are reported in Table 2. The results are classified as very poor, medium poor, poor, fair, good, very good and excellent in the Table 3. The notation and the fuzzy number of each of the six grades for both requirements for the part importance for remanufacturing and selection parameters were made with respect to triangular membership function [8]. Table 4 highlights the opinions given by decision makers on the selection of components in perspective of remanufacturing with respect to bike suspension. The same decision maker's opinion regarding the selection of components with respect to remanufacturing parameters was taken in order to enhance the design for remanufacturing as shown in the Table 5. Based on the aggregate fuzzy numbers obtained, fuzzy numbers are assigned to the linguistic variables suggested by the decision maker in the Table 6. The values of normalized fuzzy decision matrix are weighted by multiplying them with the relevant aggregated fuzzy number as shown in the Table 7 [9]. Next, the ranking of the testing parameters was obtained using the relations below.

D* represents the Fuzzy Positive Ideal Solutions (FPIS D*).

$$D^* = \Sigma \tfrac{1}{2} [max (|1^{st} - 1|; |3^{rd} - 1|) + (2^{nd} - 1)] \tag{1}$$

Here, the values $|1^{st} - 1|$ and $|3^{rd} - 1|$ from weighed normalized decision matrix are compared. The greater of the 2 values is added to $(2^{nd} -1)$.

D# represents the Fuzzy Negative Ideal Solutions (FNIS D#).

$$D\# = \Sigma \tfrac{1}{2} [max (|1^{st} b\ b; - 0|, |3^{rd} - 0|) + |2^{nd} - 0|] \tag{2}$$

Here, the values $|1^{st} - 0|$ and $|3^{rd} - 0|$ from weighed normalized decision matrix are compared. The greater of the 2 values is added to $(2^{nd} - 0)$.

$$\text{Relative closeness coefficient of strategies } (C^*) = D\#/ (D^*+ D\#) \tag{3}$$

From the Fuzzy-TOPSIS analysis, we found that roundness ranks first followed by surface roughness, weight, change in diameter, change in thickness, and change in width. The rankings and relative closeness coefficient are reported in Table 8.

Table 2
Linguistic variables and testing parameters

Parts	Description	Selection Parameters	Description
R1	Cylinder height	P1	Remanufacturing ability
R2	Piston od	P2	Quality
R3	Piston height	P3	Level of integration
R4	Cylinder ID	P4	Cost saving
R5	Stiffness	P5	EOL condition
R6	Seal ID	P6	Durability

Table 3
Design maker's opinion Requirements for remanufacturing

Requirements for remanufacturing	Description	DM1	`DM2	DM3	Aggregate Fuzzy No.
R1	Stiffness	U	V	S	(0.6333,0.8,0.9)
R2	Piston od	T	V	U	(0.7,0.866,0.9666)
R3	Piston height	U	T	V	(0.7,0.866,0.966)
R4	Cylinder ID	U	U	T	(0.633,0.833,0.966)
R5	Cylinder height	V	V	T	(0.766,0.9,0.966)
R6	Seal ID	U	U	V	(0.766,0.933,1)

Table 4
Decision maker's opinion about requirements for remanufacturing wrt testing's parameters

	P1	P2	P3	P4	P5	P6
R1	T	V	V	P	V	S
R2	V	S	U	R	V	S
R3	U	T	V	V	S	S
R4	V	V	V	U	Q	R
R5	T	U	V	R	V	T
R6	V	V	V	V	U	U

Table 5
Fuzzy Decision matrix

R1	0.50,0.70,0.9	0.90,1.00,1.0	0.9,1.00,1.0	0.00,0.00,0.1	0.90,1.00,1.0	0.30,0.50,0.7
R2	0.90,1.00,1.0	0.30,0.50,0.7	0.7,0.90,1.0	0.10,0.30,0.5	0.90,1.00,1.0	0.30,0.50,0.7
R3	0.70,0.90,1.0	0.50,0.70,0.9	0.9,1.00,1.0	0.90,1.00,1.0	0.30,0.50,0.7	0.30,0.50,0.7
R4	0.90,1.00,1.0	0.90,1.00,1.0	0.9,1.00,1.0	0.70,0.90,1.0	0.00,0.10,0.3	0.10,0.30,0.5
R5	0.50,0.70,0.9	0.70,0.90,1.0	0.9,1.00,1.0	0.10,0.30,0.5	0.90,1.00,1.0	0.50,0.70,0.9
R6	0.90,1.00,1.0	0.90,1.00,1.0	0.9,1.00,1.0	0.90,1.00,1.0	0.70,0.90,1.0	0.70,0.90,1.0

Table 6
Weighed normalized fuzzy decision matrix

R1	0.317,0.56,0.81	0.63,0.867,0.967	0.63,0.867,0.96	0.000,0.000,0.097	0.690,0.90,0.967	0.230,0.467,0.7
R2	0.570,0.80,0.90	0.21,0.433,0.677	0.49,0.780,0.96	0.063,0.250,0.483	0.690,0.90,0.967	0.230,0.467,0.7
R3	0.443,0.72,0.90	0.35,0.607,0.870	0.63,0.867,0.96	0.570,0.833,0.967	0.230,0.45,0.677	0.230,0.467,0.7
R4	0.570,0.80,0.90	0.63,0.867,0.967	0.63,0.867,0.96	0.443,0.750,0.967	0.000,0.09,0.290	0.077,0.280,0.5
R5	0.317,0.56,0.81	0.49,0.780,0.967	0.63,0.867,0.96	0.063,0.250,0.483	0.690,0.90,0.967	0.383,0.653,0.9
R6	0.570,0.80,0.90	0.63,0.867,0.967	0.63,0.867,0.96	0.570,0.833,0.967	0.537,0.81,0.967	0.537,0.840,1.0

Table 7
Relative closest coefficient of design parameters and ranking

Design Parameters	D*	D-	Ci*= Di-/(Di*+Di-)	Rank
R1	2.921667	4.083333	0.582917	4
R2	3.058333	4.161667	0.576408	6
R3	2.801667	4.511667	0.61691	3
R4	2.998333	4.121667	0.578886	5
R5	2.708333	4.551667	0.626951	2
R6	1.755	5.391667	0.754431	1

Stiffness of the spring is the important parameter which will impact the remanufacturing. Seal ID is also prone to leakage of suspension but replacement is economical in this case.

3. Taguchi Desirability Function

After deciding the critical parameters with Fuzzy TOPSIS for the optimum feasibility for remanufacturing these parameters are analysed using Taguchi Desirability Function [11]. This analysis is carried out in four steps which are – (i) Design of Experiments (DOE) (ii) selection of model (iii) analysis of responses (iv) desirability function analysis. If traditional experimental design is used very large number of experiments is required to collect the information whereas DOE endeavours to plan systematic conduction of experiments to acquire data in an intelligent and controlled manner with minimum efforts [12]. The process can be divided broadly into three parts as System; Input Factors and Responses. The system can be considered as the heart of the process. Input factors are variable signals which serve as starting mechanisms of the process [13]. Data obtained experiments designed through DOE provides the sufficient information to establish the relationship between the specified input factors and the responses of the given process. The possible values of input factors considered during experimentation are termed as levels. The selection of the input factors, their levels and responses are the most important and critical stage in the analysis. In DOE when all possible combinations of given input factor levels are considered, it is termed as a full factorial design (FFD) [14]. The main effect model needs a smaller number of experiments than its extension. Each experiment corresponds to a set of responses. The response values acquired from comparatively few experiments enables response prediction for FFD. As this is a multi-response optimization problem, a popular simultaneous optimization approach is employed. The optimal solutions were arranged in the descending order of their combined desirability value [15]. This feature of Taguchi analysis can be used to acquire multiple optimal solutions. In this paper Design-Expert version 11 software was used for the implementation of Taguchi Analysis.

Table 8
Constraints for Taguchi desirability analysis

Name	Goal	Lower Limit	Upper Limit	Importance
Stiffness	Maximize	234750	257833	3
Piston od	Minimize	15.7	15.94	3
Piston height	Minimize	153	154.5	3
Cylinder ID	Minimize	11.667	11.83	3
Cylinder height	Minimize	183.5	186.77	3
Seal ID	Minimize	3.84	3.91	3

Table 9
Results of desirability analysis for bike suspension

No.	Stiffness	Piston od	Piston height	Cylinder ID	Cylinder height	Seal ID	Desirability
1	254720.000	15.700	153.000	11.672	186.200	3.900	0.525
2	248554.000	15.650	154.100	11.803	185.600	3.850	0.448
3	268524.000	15.460	152.600	11.677	185.800	3.910	0.004
4	240916.000	15.940	153.400	11.667	186.600	3.890	0.002

From the Figure 3, the combined desirability ratio of suspension 1 is 0.524 whereas the piston OD and the piston height has the highest desirability ratio of 1 and seal ID has the lowest desirability ratio of 0.142. From the Figure 4, the combined desirability ratio of suspension 2 is 0.448 whereas the piston OD has the highest desirability ratio of 1 and Cylinder ID has the lowest desirability ratio of 0.165.

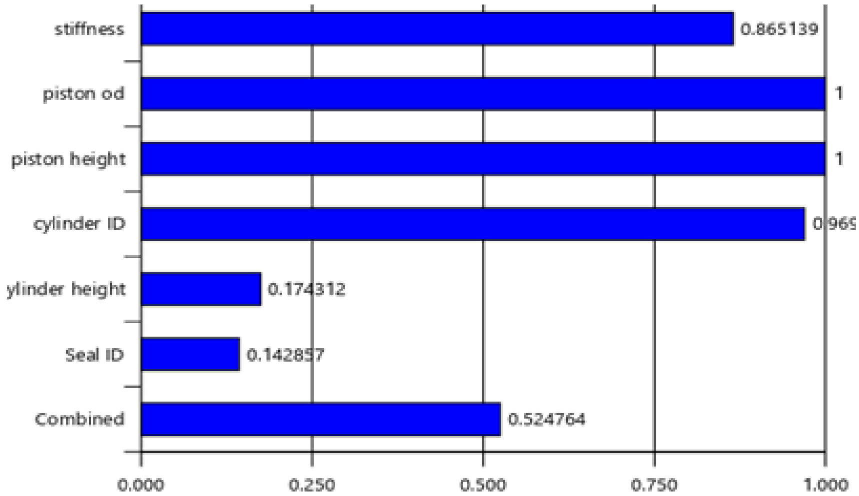

Fig. 3. Desirability chart for Suspension 1

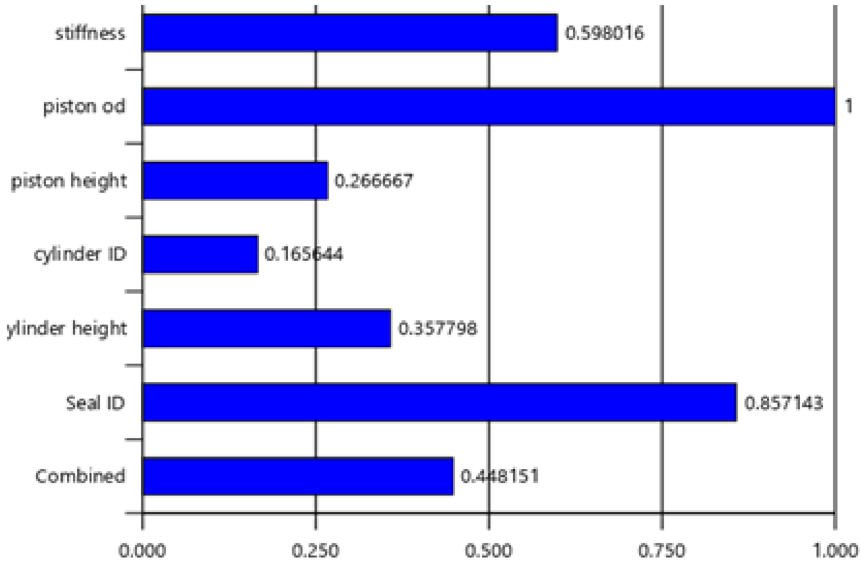

Fig. 4. Desirability chart for Suspension 2

From the Figure 5, the combined desirability ratio of suspension 3 is 0.004 whereas the Stiffness, piston OD, piston height has the highest desirability ratio of 1 and Seal ID has the very low desirability ratio almost negligible. From the Figure 6, the combined desirability ratio of suspension 1 is 0.001 whereas the cylinder ID has the highest desirability ratio of 1 and Piston OD has the very low desirability ratio almost negligible.

As per the desirability analysis seal internal diameter is the highly influential parameter followed by cylinder internal diameter and stiffness of the spring, whereas the piston outer diameter, piston height has the least influential parameters for design for remanufacturing for bike suspension. Out of the four bike suspension, two bike suspension has the highest desirability ratio which means 50% of the bike suspensions are good for remanufacturing.

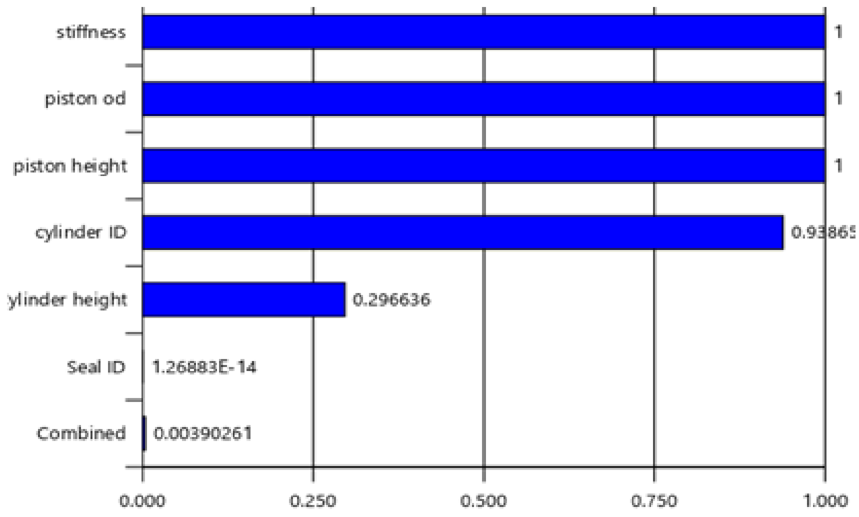

Fig. 5. Desirability chart for Suspension 3

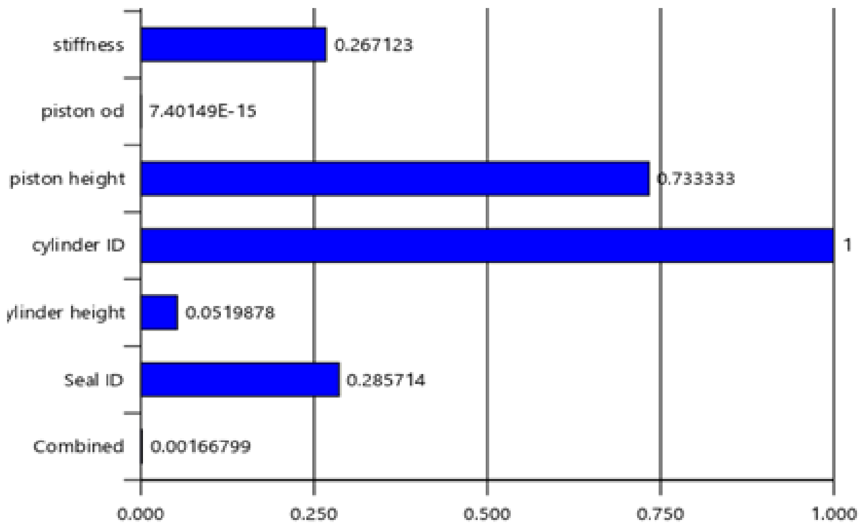

Fig. 6. Desirability chart for Suspension 4

4. Conclusions

By applying the Taguchi desirability curves, we can understand the feasibility of Bike suspensions for Design for remanufacturing. By our analysis we are able to get an optimum desirability of 0.525 giving maximum importance selected important parameters. Where if suspension has more than 50%

combined desirability will be selected. Remanufacturing of bike suspension will be effective in Indian region but due to excessive wear of the component's selection process becomes critical. As per the desirability analysis seal internal diameter is the highly influential parameter, whereas piston outer diameter, has the least influential parameters for design for remanufacturing for bike suspension. In both the fuzzy analysis and Taguchi desirability function analysis, the seal internal diameter is identified as the most influential parameters which indicates the designer of bike suspension need to concern more on seal internal diameter retention after end of life. Overall, two bike suspension seems to be fit for remanufacturing.in future we need to go for carrying out the analysis with more samples. More samples can give a better conclusion of identification of the influential parameters for the design for remanufacturing.

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