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Modification Design of a Reverse Gear Box Coupler for an RL 15 Motorized Railway Trolley.

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ABSTRACT
The frequent failures of the coupling assembly (coupler) of the motorized railway trolley poses a big challenge to maintenance work on railway tracks, which leads to a prolonged downtime period thereby affecting the normal scheduled operations of railway transport in Nigeria. In this research, an improvised coupler was modified to enhance the motorized railway trolley durability and performance under operating condition. The results of the alignment test carried out revealed a slight deflection of 0.5-inch gap from the acceptable standard of 5.0 inch for the male shaft, and the female shaft revealed a slight deflection of 0.3 inch offset per inch spacer length. The modified coupler was designed using SOLIDWORKS design software. Stress and fatigue analysis was carried out on the existing coupler and the modified one. The modified coupler exhibited better performance and also proved to be safer under operational condition when compared with the existing one.

Keywords: Frequent failures, motorized railway trolley, modified coupler, better performance.

I. INTRODUCTION

A coupler is a mechanical device that connects similar or dissimilar shafts in machines to transmit power and movement. It is usually a temporary connection, although permanent in some cases, capable for service or replacement [1]. Shaft couplings play a very key role in power transmission. Causes of coupling failure include; improper manufacturing, incorrect installation, poor maintenance, human errors, and service conditions such as; wear, fatigue and shaft failure [2]. Coupling materials include metals and their alloys, such as iron, steel, copperand non-metals, such as: rubber, plastics.

The railway transportation has existed for over 116 years in Nigeria with over 30 years of the use of manually operated rail trolleys used for railway track maintenance. Presently, modern rail trolleys manufactured by China Railway Shanhaiguan Bridge Group Company Limited are being used. The motorized railway trolley is used for line-section inspection, conveyance of light machines, tools and workers transportation on rail tracks, consists of the male-coupling, rubber-damper, female-coupling and a cone (cover) as shown in Plate I. The coupling assembly receives torque from the main engine and transmits same to the reverse gearbox, down to the axle of the motorized railway trolley. The rubber-damper houses the male and the female couplings as shown in the cross sectional view of Plate II. The damaged components comprise of the pinion, rubber-damper and coupling as shown in Plate III.The rate of frequent failure of components of the railway trolley such as the reverse-gearbox and coupling poses a very big challenge to maintenance work. Hence, the objective of this paper is to modify the design of the couplerwith a view ofenhancing its performance and durability during operation.

Plate I: Coupling Assembly

Plate II: Cross sectional view of coupler showing failed rubber-damper, and fingers of the male-coupling and Cone

Plate III;Pinion, coupling and rubber damper.

II. MATERIALS AND METHODS

1.1 Material and Equipment

The materials used for this work were sample of the failed couplers, and the equipment used wereVernier caliper, and Dial indicator.

2.2 Methods

2.2.1 Visual Inspection

The failed components of the couplerwere visually examined and identified.

2.2.2 Alignment Test

The dial indicator was used to measure the alignments of the shafts of the male and female couplings. The inch values gap difference per 10 inch coupling diameter, and the inch values offset per inch spacer length of the coupling shafts were measured and recorded.

2.3 Modification ofImprovised Coupler

To surmount the challenge of incessant failure of the existing coupler, an improvised version was developed by the use of a universal joint (refer to Plate IV) to serve as a test prototype. It is also worth noting that the improvised coupler was a temporary solution that was done without a design. Hence, the universal joint does not require the use of a rubber-damper for its operation, and the improvised coupler was tested to cover a rail distance of 72 KM.It gave better output than the existing coupler under the same operational conditions. However, the modified coupler was later designed and improved upon using SOLIDWORKS software to design for durability.

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Plate IV: Improvised coupler

2.3.3 Simulation of Modified Coupler

The Finite Element was used to analyse the modified coupler. The models were designed using SOLIDWORKS application, and meshed in three degrees of freedom per node. The dimensions, sizes and material properties of the models conform to the real-world coupler. SOLIDWORKS simulation and fatigue analysis were carried out to ensure that the component performs efficiently, and evaluate the component structural durability to withstand cyclic loading condition when put to use under real operational conditions.

2.3.4Exploded View of Modified Coupler

The exploded view of the modified coupler is presented in Figure 1. The figure shows the components as well as the relationship between the parts and how they fit together.

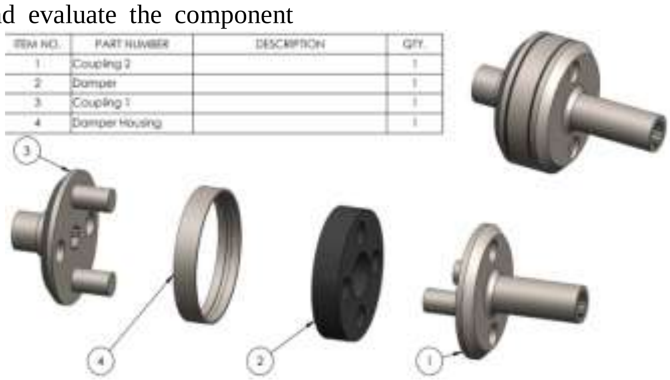

Figure 1: Exploded View of Modified Coupler

2.3.5Material Properties of Modified Coupler.

The material properties of the couplings and rubber-damper models are presented in Table 1. The specific materials properties for the coupler and rubber damper are identified and listed as follows:

i. The material properties of coupler are; ASTM A36 steel, tensile strength 4e+08 N/m^2, Yield strength 2.5e+08N/m^2, Elastic modulus 2e+11 N/m^2, Poisson's ratio 0.26, Mass density 7850 Kg/m^3 and Shear modulus 7.93e+10N/m^2.
ii. The rubber-damper material properties are: Tensile strength 1.37871e+07 N/m^2, Yield strength 9.23737e+06 N/m^2, Elastic modulus 6.1e+06 N/m^2, Poisson's ratio 0.49, Mass density 1000 Kg/m^3, Shear modulus 2.9e+06 N/m^2 and Thermal expansion coefficient 0.00067/ Kelvin [4]. While the load applied is presented in Table 2.

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Table 1**: Material Properties of Modified Coupler**

Model Reference	Properties	Components
	Name: ASTM A36 Steel Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 2.5e+08 N/m^2 Tensile strength: 4e+08 N/m^2 Elastic modulus: 2e+11 N/m^2 Poisson's ratio: 0.26 Mass density: 7,850 kg/m^3 Shear modulus: 7.93e+10 N/m^2	SolidBody 1(Cut-Extrude2)(Coupling 1-1), SolidBody 1(Cut-Extrude3)(Coupling 2-1), SolidBody 1(Cut-Revolve1)(Damper Housing-2)
Curve Data:N/A		
	Name: Rubber Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 9.23737e+06 N/m^2 Tensile strength: 1.37871e+07 N/m^2 Elastic modulus: 6.1e+06 N/m^2 Poisson's ratio: 0.49 Mass density: 1,000 kg/m^3 Shear modulus: 2.9e+06 N/m^2 Thermal expansion coefficient: 0.00067 /Kelvin	SolidBody 1(Cut-Extrude1)(Damper-1)
Curve Data:N/A		

Table 2: **Load Applied on the Modified Coupler**

Load name	Load Details	
Torque-1	Reference:	**Face< 1 >**
	Type:	**Apply torque**
	Value:	**15 Nm**

III. RESULTS AND DISCUSSION

3.1 Alignment Results

The dial indicator was used for the alignment test, and the result is presented in Table 3. From the result, it could be observed that the gap difference per 10 inch coupling diameter for the male-coupling shaft was 5.5 inch, and the offset per inch spacer length for the female-coupling shaft was 0.7 inch. The result also revealed a slight deflection of 0.5-inch gap from the acceptable standard of 5.0 inch for the male shaft, and the female shaft revealed a slight deflection of 0.3 inch offset per inch spacer length. The misalignments that occurred was likely to have contributed to the inadequate meshing of the gear teeth which could in itself lead to failure. The shafts gap difference and offset were also remedied.

Table 3: Results of Alignment Test of Failed Coupling Shafts.

RPM	**INCH (MILS) Coupling Shafts**	**INCH (MILS) Acceptable**	**Excellent**
Inch values – Gap difference per 10inch coupling diameter	5.5	5.0	3.0
Inch values - Offset per inch spacer length	0.7	1.0	0.6

3.2Simulation of Existing Coupler

The result of the stress analysis of existing coupler when subjected to operational conditions, is presented in Table 4.

3.3 Modification of ExistingCoupler

3.3.1Mesh Model and Mesh Details of Existing Coupler

The mesh model of existing coupler is presented in Figure 2 and the mesh details are presented in Table 4. From the table, it could be seen that the mesh properties comprise; Total nodes 13585, Total elements 8274, Maximum aspect ratio

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5.2096, % of element with aspect ratio < 3 was 98.3, % of element with aspect ratio > 10 was 0, and Time to complete mesh was 3 seconds [5].

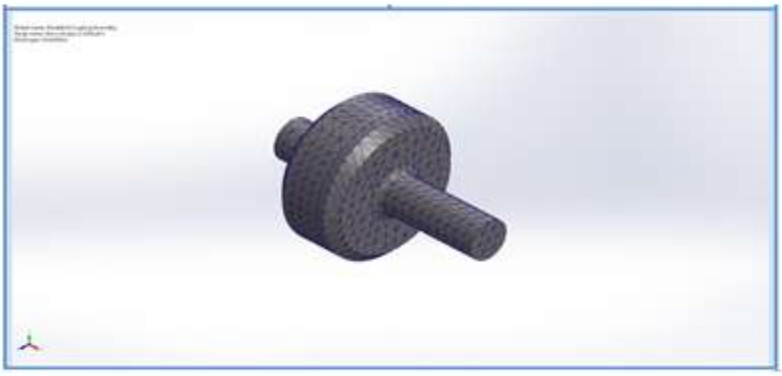

Figure 2: Mesh Model of Modified Coupler

Table 4: Mesh Details of Existing Coupler

Properties	**Values**
Total Nodes	13585
Total Elements	8274
Maximum Aspect Ratio	5.2096
% of elements with Aspect Ratio < 3	98.3
% of elements with Aspect Ratio > 10	0
% of distorted elements (Jacobian)	0
Time to complete mesh (hh;mm;ss):	00:00:03

3.4Stress Analysis Results of Existing Coupler

The existing coupler when subjected to operational conditions, the result of the stress analysis is presented in Table 5. The result indicated that the existing coupler would fail at the middle as shown in Figure 3. The red colours signified the failure-prone area[6].

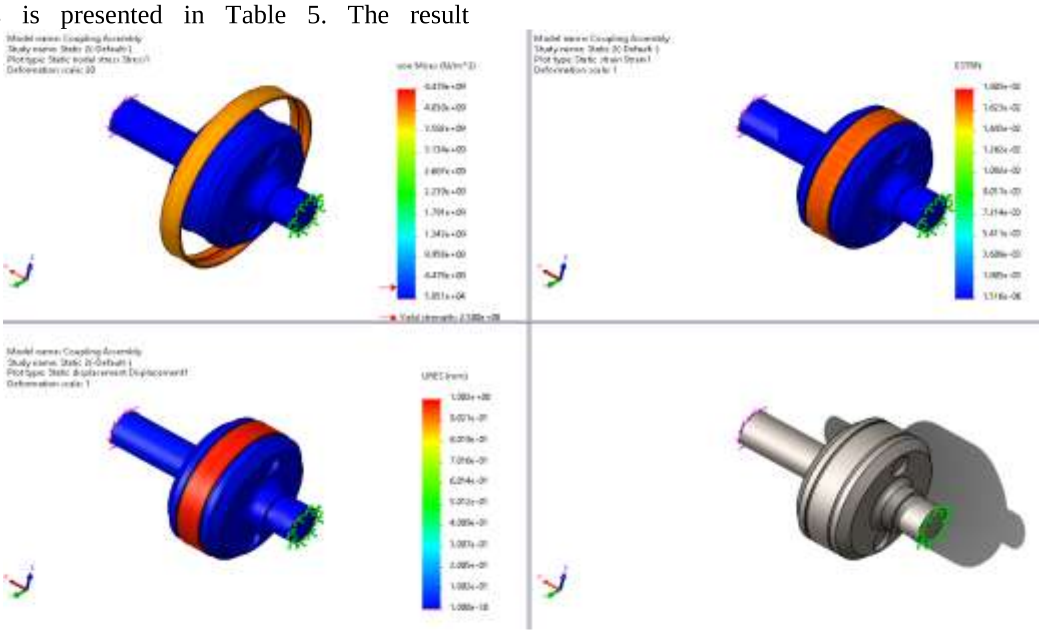

Figure 3: Stress Analysis of Existing Coupler

Table 5:Static Result of Existing Coupler

	MINIMUM	MAXIMUM
STRESS (von Mises)	5.851e+04(N/m^2)	4.478e+09(N/m^2)
DISPLACEMENT (URES)	1.000e-30(mm)	1.002e+00(mm)
STRAIN (ESTRN)	1.516e-06	1.803e-02

3.5Fatigue analysis of Existing Coupler

The result of Fatigue Analysis is presented in Table 6. The result also indicated that after some operational cycles, the coupler would be damaged in the middle part as shown in Figure 4.The red colour signifies the failure-prone areaarea [7].

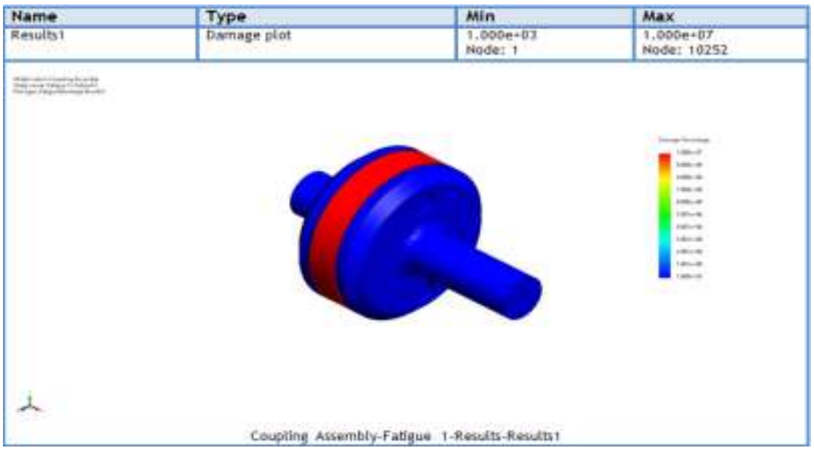

Figure 4: Damage Analysis of Existing Coupler

Table 6:Fatigue Result of Existing Coupler

	MINIMUM	MAXIMUM
DAMAGE PERCENTAGE	1.000e+3	1.000e+07
TOTAL LIFE	1.000e+02 Cycle	1.000e+06 Cycle

Further analysis confirmed that the middle part of the coupler would fail after some few cycles of operation while the other part of the same couplings would operate without failing for more than a million cycles as indicated in Figure 5. The blue colour signifies the damage or failure-prone area [7, 8].

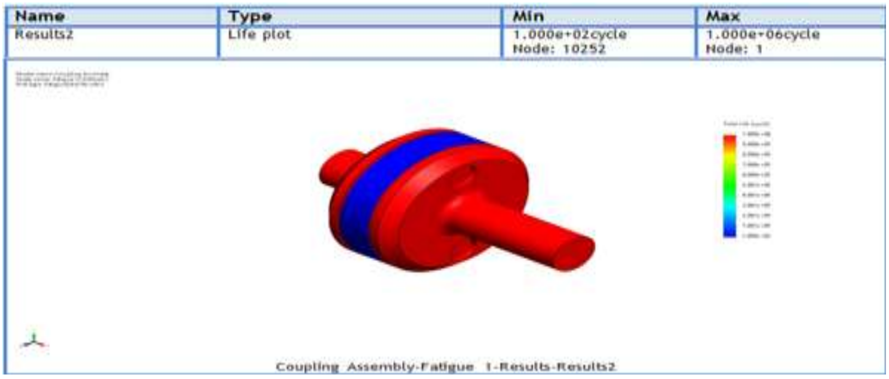

Figure 5: Life Analysis of Existing Coupler

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From the result presented in Tables 6, the damage percentage 1.000 e+3 minimum and 1.000 e+07 maximum was high and would be necessary to modify the Coupling System to solve the problems. However, the modification would have to conform to the dimensions of the existing couplings of the MRT trolley.

3.6 Modeling and Simulation of Modified Coupler.

3.6.1 The **SOLIDWORKSDesign.**

Solidworks software was used for the design. The modified designs of the coupler are presented in Figures 6 and 7. They clearly showed the dimension and accurately captured the geometric features of the modified coupler [9].

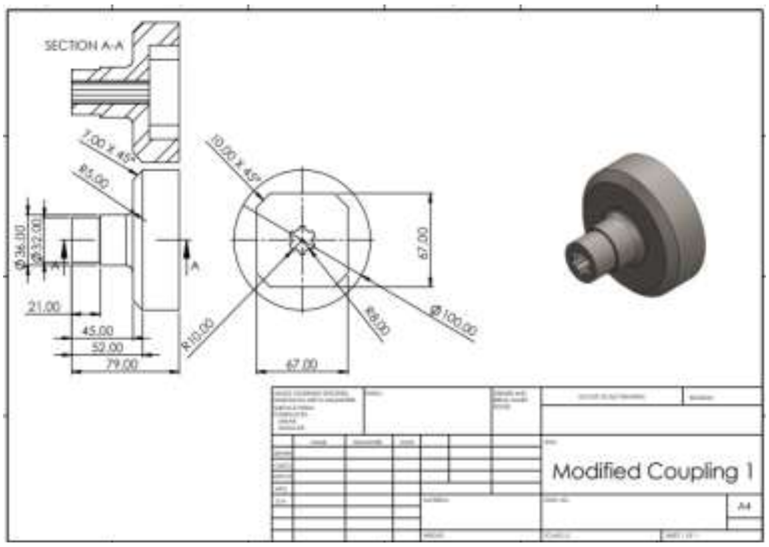

Figure 6: Solidworks Drawing of Modified Coupling Assembly (Male)

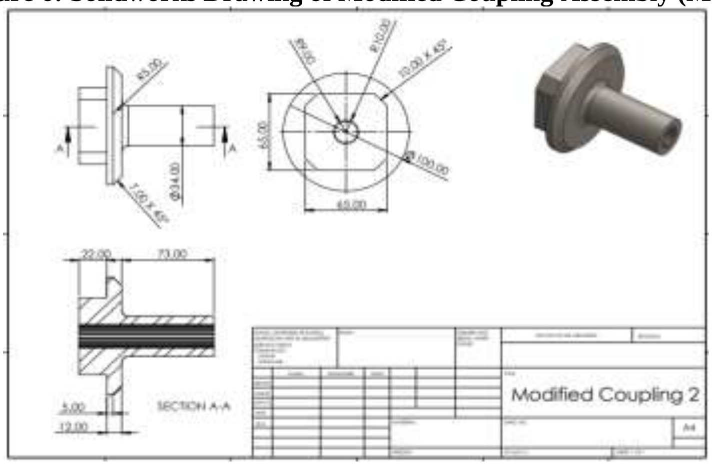

Figure 7: Solidworks Drawing of Modified Coupling Assembly (Female)

3.6.2 Exploded Views of Modified Coupler

The exploded views of the modified coupling assembly are presented in Figure 8. The views show the modified couplings, and how they fit together.

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Figure 8: Solidworks Exploded View of Modified Coupler

3.6.3Stress Analysis of Modified Coupling Assembly

The result of the stress analysis of the modified coupler when subjected to operational conditions, is presented in Table 7. The result has sufficiently revealed that the modified coupling system would be safe for operational use and less failure-prone (refer to Figure 9), as the blue colours would indicate [10].

Table 7:Static Result of Modified Coupler.

	MINIMUM	MAXIMUM
STRESS (Von Mises)	1.7351 e+03 (N/m^2)	6.365 e+06 (N/m^2)
DISPLACEMENT (URES)	1.000 e-30 (mm)	2.329 e-03 (mm)
STRAIN (ESTRN)	2.675 e-09	1.985 e-05

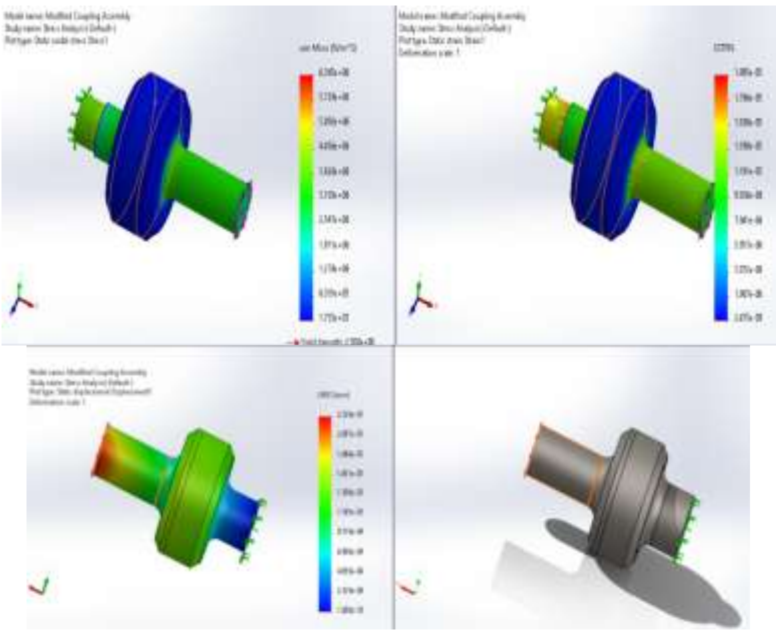

Figure 9: Stress Analysis of Modified Coupler.

3.6.4Fatigue Analyses of Modified Coupler.

The result of Fatigue Analysis is presented in Table 8. The result also confirmed that the design was safe under operational conditions [11] - as the blue colour of the legend did indicate zero damage percentage in Figure 10.

Table 8:Fatigue Result of Modified Coupler

	MINIMUM	MAXIMUM
DAMAGE PERCENTAGE	9.000 e+02	9.009 e+02
TOTAL LIFE	1.000e+06 Cycle	1.001e+06 Cycle

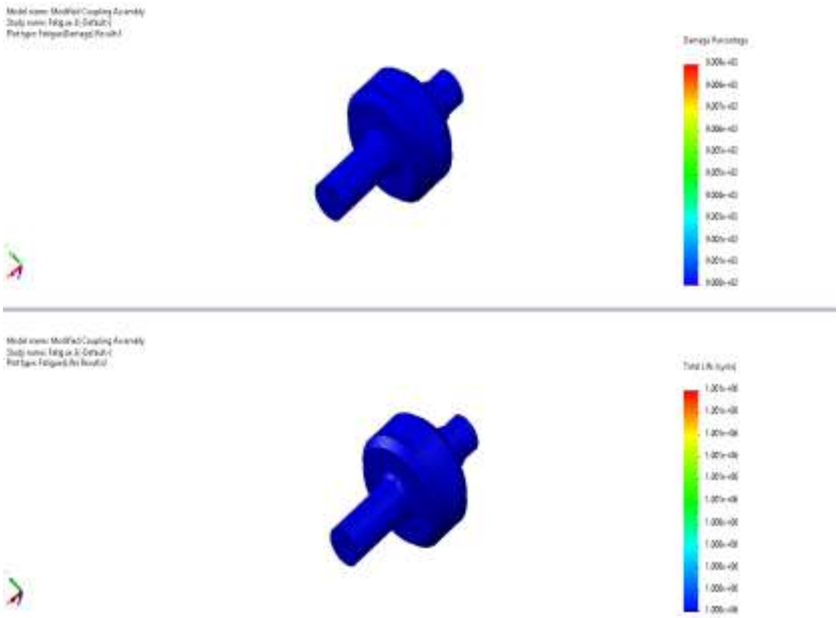

Figure 10: Damage and Life Analyses of Modified Coupler

From the result in Table8, the damage percentage of 9.000 e+02 minimum and 9.009 e+02 maximum are inconsequential. The modified coupler is safe and would be a better replacement to the real-life coupler with sufficient proof to deliver safe operational application under the operational conditions [11, 12]. Therefore, the modified coupler is hereby recommended to replace the existing coupler for improved output for the MRT.

IV. CONCLUSION

In this study, the coupling system of RL-15 MRT was modified and improved upon to eliminate frequent failures and enhance performance and durability during operation. The following could be concluded from the research:

i. The visual examination suggests that the rubber-damper appears not to be tough enough for transmitting large level torque and motion between the couplings assembly.
ii. The alignment test revealed a slight deflection of 0.5-inch gap difference per 10 inch coupling diameter, and 0.3 inch offset per inch spacer length on the coupling shafts.
iii. Using SOLIDWORKS simulation and under the same operating conditions, the modified coupling assembly has proven to be safe and more durable than the existing coupler.
iv. The modified coupler is hereby recommended to replace the existing coupler for improved output for the MRT on account of its safety profile, durability, and convenience in use in operating condition.

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