Design of Waste Tyre Flexible Couplings for Generating Plant

B. Kareem, A. S. Lawal, S. Drisu

***Abstract**: There is a growing need at creating wealth from wastes. Waste tyres have been littering our environment. There is need to create ways of utilizing them effectively after their critical mechanical properties have been investigated. Flexible couplings made of waste tyres were designed using power ratings and service factors of generating plant. Coupling sizes, dimensions, among other physical properties were selected at varying Internal Combustion Engine (ICE) speeds; 1000, 2000 and 3000 rpm, from which the choices of waste tyre couplings were made. The results of over 16 hours of running of the generating plant using coupling size F 60 selected based on service factor (1.5), engine speed (1000 rpm), bore diameters (42-48 mm) and power rating (11.10 kW) performed satisfactorily. Therefore, the waste tyre flexible couplings are capable of transmitting power/torque from the generating plant without failure within the test hours.*

***Keywords**: Waste tyres, Service factor, Design ratings, Coupling choice*

I. INTRODUCTION

The power generation is the backbone of every country to survive. Electricity generation is the process of generating electrical power from other sources of primary energy [1]. Central power stations became economically practical with the development of alternating current (AC) power transmission, using power transformers to transmit power at high voltage and with low loss. Commercial electricity production started with the coupling of the dynamo to the hydraulic turbine. The first power plants used water power or coal. Today a variety of energy sources are used, such as coal, nuclear, natural gas, hydroelectric, wind, and oil, as well as solar energy, tidal power, and geothermal sources [2]. Inventions such as the steam turbine had a massive impact on the efficiency of electrical generation but also the economics of generation as well. The improvements of these large-scale generation plants were critical to the process of centralized generation as they would become vital to the entire power systems that are use today. Alternator means generator's rotor drive or move by engine.

Manuscript received on 25 May 2023 | Revised Manuscript received on 05 June 2023 | Manuscript Accepted on 15 June 2023 | Manuscript published on 30 June 2023.
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An alternator is an electromechanical device that converts mechanical energy to electrical in the form of alternating current. Most alternators use a rotating magnetic field with a stationary armature but occasionally, a rotating armature is used with a stationary magnetic field, or a linear alternator is used [2]. The main aim is to move and drive the rotor by an Internal Combustion Engine (ICE) to produce electric power.

With the rate of failure of non-availability of Power (Electricity) and dwindling energy sources, generation of energy sources, generation of energy in a cost effective manner with minimum waste and environmental footprint becomes one of the greatest challenges of our time [2]. There is an increasing need for more capable and intelligent use of energy sources by incorporating enriched design and optimized algorithms to enhance the sustainability of power generating system through innovative solution. In this regards, the method and tools is to design a flexible coupling system using waste tyres for power/torque transmission in generating plant thereby turning waste to wealth. Design of a flexible coupling made of waste tyres can go a long way in addressing this challenge of tyre wastes accumulation in the environment. The specific objectives are to: design flexible couplings that utilise waste tyre materials for a generating plant; and evaluate the performance of the designed flexible couplings. A design of tyre flexible coupling was carried out capable of transmitting 5-30 kW power from a Internal Combustion Engine (ICE) to the alternator within a speed range of 1000- 3000 rpm.

A coupling is a device that connects two shafts for the transmission of power, or torque, and it can be rigid or flexible [3]. The couplings are useful in driving or driven shafts found in motors, pumps, generators, and compressors, among others[4]. Common types of couplings and their functions can be found in [5]. The one that is critical to this study is flexible couplings that connect two shafts of the Internal Combustion Engine (driver) and alternator (driven) to generate electric power[6; 7]. A few examples of flexible couplings are bushed pin-type couplings, universal couplings, Oldham couplings, gear couplings, bellow couplings, jaw couplings, diaphragm couplings and tyre couplings. Tyre flexible coupling type was considered in this study because it is relatively cheap as waste materials. Other drives include; belt drive, rope drive, chain drive, and gear drive [8; 9], but these are very costly to apply.

II. METHODOLOGY

A. Flexible Couplings Basic Design Properties

The following mechanical properties of the flexible couplings were considered:

- **Rated torque;** is the maximum service torque for which the coupling is rated.
- **Rated speed;** is the maximum rated rotational speed of the coupling.

The following critical dimensions of the flexible couplings were also considered:

- **Bore diameter,** is the internal diameter for mating to the motor or shaft-end.
- **Coupling diameter**; is the outside diameter (OD) of the coupling and includes the housing, etc.
- **Coupling length;** refers to the overall length of the flexible coupling.
- **Design units**; can be specified in English or metric.

Alignment and motion parameters considered are:

- **Angular misalignment tolerance;** is the maximum angular misalignment between coupled shafts that flexible couplings can accommodate.
- **Parallel misalignment tolerance;** is the maximum parallel offset between shafts that couplings can accommodate.
- **Axial motion** allowed; refers to the relative axial motion allowed by the coupler between shafts.
- **Operating temperature;** is an important environmental parameter to consider when designing or searching for flexible couplings.

B. Design of Couplings for 5-30 kW Power Generating Plant

The aim is to design tyre couplings that can transmit 5-30kW from a changeable speed (1000-3000 rpm) internal combustion engine to a rotary alternator for over 16 hours a day. The engine shaft is 40mm and the alternator (rotor) shaft is 45 mm diameter. Dimensions shown in [10] are considered as basis for the tyre couplings design. The design schematic configuration that shows the relationship between the engine, the type couplings and the alternator is shown in Fig. 1.

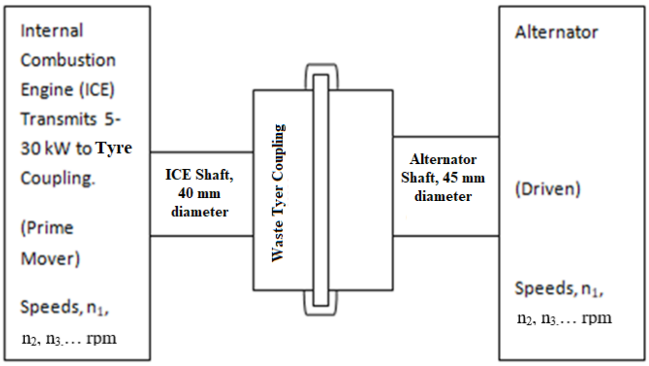

Fig. 1 Relationship between engine, coupling and alternator.

C. Reasons for Tyre Coupling Design Choice

Reasons for tyre coupling design choice are:

- Waste tyre materials can be put into productive use. That is waste to wealth
- Tyre natural rubber can perform operationally in ambient and adverse temperatures ranging between -50°C and +50°C and -15°C and 70°C, respectively [10].
- It has fire resistance and antistatic properties in most cases.
- It has torque capacity up to 12606 Nm, and bore diameters up to 190 mm in service [10].
- It is flexible and capable of handling and compensating for parallel misalignment up to 6 mm, angular misalignment up to 4° and end float up to 8 mm [10].
- It is torsionally soft and has ability of cushioning against destructive shock loads protecting the complete system, preventing unexpected breakdowns and thereby sustaining machine life.
- It is free of backlash, and does not create snatch on take up of the drive.
- It is easy to install and requires simple tools and skills during installation. The split flexible tyre straps are positioned in the flanges and the screws tightened into place (hub).
- The tyre coupling reduces vibration and torsional oscillations developed in internal combustion engine (ICE) which increases with the ICE speeds.
- The tyre compling is easily removable and replaceable.
- It is useful in adverse operating environment.

D. Requirements for Coupling Design

The following requirements were considered in tyre coupling design:

- Number of operating hours per day and type of driven machine.
- Magnitude of speed and power absorbed by driven machine.
- Diameters of shafts (driver and driven) to be connected.

E. Design Procedure

The design procedures are as follows:

- Required service factors are determined based on the class of driver and driven systems. This was selected based on flexible tyre coupling design standards [10].
- Computation of tyre coupling design power was done by multiplying the normal running power by the service factor. The design power obtained formed the basis for selecting the standard coupling [10].
- On the basis of (ii), coupling sizes were obtained by reading across [10] from the appropriate speeds until a power greater than that required in (ii) was found.
- The sizes of tyre couplings required were found at the head of that column [10].
- Dimension tables were checked for the chosen flanges to accommodate required bores [10].
- Design dimensions for the standard couplings, F, H and/or B types are given by [10].

F. Tyre Coupling Design

In reference to section B and Fig. 1, the design procedure (section E) was applied as follows:

- Service Factor (SF) determination: The waste tyre couplings are to be applied in power generators to flexibly connecting internal combustion engines to the alternators (Fig. 1). For best performance, service factor that correspond to minimum of sixteen (16) running hours of internal combustion engine was selected [10].

Retrieval Number:100.1/ijeat.E41940612523
DOI: 10.35940/ijeat.E4194.0612523
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Hence, service factor is 1.5.

- Design Power (DP): On the basis of section E, the Design Power (DP) was computed based on Normal Running Power (NRP) and Service Factor (SF) as in Eqn. 1, and the outcomes were compared to the standards.

$$DP=NRP \times SF \quad (1)$$

Table 1 shows the results obtained for Design Power, by varying Normal Running Power in step of 5 and for the established Service Factor (1.5). For instance, the first step;

$$DP=5kW \times 1.5=7.5kW \quad (2)$$

- Coupling sizes: By varying ICE speeds form 1000 rpm – 3000 rpm in step of 1000 rpm as required for normal electric power voltage generation (210-240 V), the standard coupling sizes and power ratings were selected from [10]. The couplings standard design sizes and power ratings selected at varying running speeds are presented in Table 2. For example, by reading across from 1000 rpm in [10], the first figure to exceed the required power 7.5 kW in step (ii) is 11.10 kW. The size of the coupling is F 60.
- Bore Sizes: With reference to [10], at a speed of 1000 rpm and design power of 7.5 kW, for example, it was revealed that both shafts (ICE and Alternator) diameters (40 - 45 mm) fell within the bore range available (42-48 mm) (Table 3).
- Standard design dimensions were also obtained for the selected coupling types (F & H and B) as shown in [10].
- Coupling standard physical characteristics; namely, torque, torsional stiffness, and maximum allowable misalignment were also selected for the best chosen couplings as highlighted in (Fenner, 2023).
- The selected couplings were designed so as to withstand the running speed of the engine (1000- 3000 rpm). The maximum allowable speeds of the engine at each of power ratings are given in Table 4.

G. Performance Evaluation

Performance Evaluation was carried out by adopting a modified F 60 flexible coupling standard which has a power rating of 7.5 kW. Waste tyre, hub, flanges, key and keyway, bolts, nuts and other critical components were made to follow standard dimension of F 60 flexible company. The test was carried out using acceptable specifications of the F 60 design. The test arrangement is shown in Fig. 2.

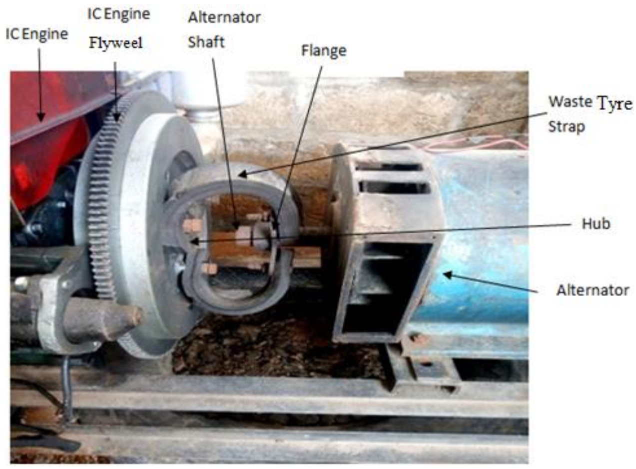

Fig. 2 Waste tyre coupling system test arrangement

Table- I: Design Power Computation at Varying Normal Running Power

Engine Normal Running Power (kW)	Service Factor	Design Power (kW)
5	1.5	7.5
10	1.5	15.0
15	1.5	22.5
20	1.5	30.0
25	1.5	37.5
30	1.5	45.0

Table- II: Coupling Design Power Ratings and Sizes Selection

Design Power (kW)	Engine Speed (rpm)/ Recommended Design Power (kW) Power and Coupling Size		
	1000	*2000*	*3000*
7.5	11.10/F 60	7.8/ F 45	11.0/ F45
15.0	17.0/F 70	22.20/ F 60	16.70/F 50
22.5	26.50/F 80	33.90/F 70	33.30/F 60
30.0	32.0/F 85	33.90/F 70	33.30/F 60
37.5	38.20/F 90	53.00/F 80	50.90/F 70
45.0	52.90/F 100	53.00/F 80	50.90/F 70

Table- III: Coupling Design Power and Allowable Bore Diameter Selection

Design Power (kW)	Engine Speed (rpm)/ Recommended Bore Diameter (mm) Range for Engine and Alternator Dia. 40 mm and 45 mm, respectively		
	1000	*2000*	*3000*
7.5	42-48	28-32	28-32
15.0	42-55	42-48	32-38
22.5	50-65	42-55	42-48
30.0	50-70	42-55	42-48
37.5	60-76	50-65	42-55
45.0	60-85	50-65	42-55

Table- IV: Design Power and Maximum Allowable Speed

Design Power (kW)	Engine Speed (rpm)/ Maximum Allowable Speed (rpm) and Coupling Size		
	1000	*2000*	*3000*
7.5	4000/F 60	4500/ F 45	4500/ F45
15.0	3600/F 70	4000/ F 60	4500/F 50
22.5	3100/F 80	3600/F 70	4000/F 60
30.0	3000/F 85	3600/F 70	3600/F 60
37.5	2880/F 90	3100/F 80	3600/F 70
45.0	2600/F 100	3100/F 80	3600/F 70

III. RESULTS AND DISCUSSION

The results of the best service factors for different power ratings of the waste tyre coupling systems are presented in Table 1. It was shown that service factor of 1.5 was adequate for all categories of power ratings varied from 7.5 kW to 45 kW. This is corresponding to minimum of sixteen (16) running hours of internal combustion engine. The selected power ratings and standard coupling sizes by varying ICE speeds form 1000 rpm – 3000 rpm in step of 1000 rpm as required for normal electric power voltage generation (210-240 V) are presented in Table 2.

It was revealed that, for example, at a speed of 1000 rpm, the first figure to exceed the required power ratings 7.5 kW was 11.10 kW. This enabled the best choice of coupling size F 60. Similarly, at a speed of 1000 rpm and design power of 7.5 kW, for example, it was revealed that both shaft diameters (ICE and Alternator) of range (40 - 45 mm) fell within the bores range available (42- 48 mm) as shown in Table 3. Hence, the selected bore range is adequate to fit the shafts of the engine and alternator. Waste tyre couplings produced using standard design dimensions were adequately power the generating plant as shown in Fig 2. Couplings standard physical characteristics; namely, torque, torsional stiffness, and maximum allowable misalignment were met in the waste tyre couplings produced and able to withstand the maximum allowable speeds of the engine at each of power ratings.

Performance evaluation of designed coupling showed at F 60 tyre couplings can be modified using waste tyre and can perform adequately in transmitting powers/torques from the engine to the alternator provided that all standard dimension as regards critical components; namely, hub, flanges, key and keyway, bolts, and nuts are strictly adhered to (Fig. 2).

IV. CONCLUSION

This study has provided a method of solving the problem of waste tyres that littering our environment by finding a critical industrial and mechanical area where these wastes can be put into use. In this study, a flexible coupling made of waste tyres was developed and its performance evaluated. From the results obtained the following conclusions can be drawn:

- The designed flexible couplings using waste tyres were capable of transmitting power/torque from the generating plant for over 16 hours without failure.
- It was shown that service factor of 1.5 was adequate for all categories of power ratings transmitted by the couplings between the internal combustion engine and the alternator.
- It was revealed that best choice of power ratings varied with the speeds of internal combustion engine and higher than estimated coupling power ratings.
- In most cases, the standard bores of the couplings fell within the available shaft diameters of the engine and the alternator.
- It was established that waste tyre couplings produced using standard design dimensions were adequate in powering the generating plant.
- F 60 tyre couplings can be modified using waste tyre and can perform adequately in transmitting powers/torques from the engine to the alternator provided that all standard dimensions were met.

From this study the following recommendation can be made:

- The use of waste truck tyres are commended for making flexible couplings locally. This will promote localization of industries.
- The use of flexible couplings in generating plant should be encouraged since it was found adequate to transmit all categories of power ratings between the internal combustion engine and the alternator.
- It is recommended that IC engine speeds should be selected based on power ratings of the installed coupling to avoid failure.
- F 60 tyre couplings were recommended for adoption of waste tyre because of its good performance in transmitting powers/torques from the engine to the alternator.
- Further study is recommended in the area of testing for the integrity of materials involved and compares them to the standards.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive any grant for the work.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	B. Kareem did the design and involved in techincal accuracy of work. A.S. Lawal conducted literature review and manuscript drafting, while S. Drisu carried out the experiment and the first drafting.

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