Design of Waste Tyre Flexible Couplings for Generating Plant

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

Abstract*: There is a growing need to create wealth from waste. Waste tyres have been littering our environment. There is need to develop ways of utilizing them effectively after their critical mechanical properties have been investigated. Flexible couplings made from waste tyres were designed using the power ratings and service factors of the 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 and torque from the generating plant without failure within the test hours.

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

I. INTRODUCTION

Power generation is the backbone of every country's survival and economic stability. 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 both the efficiency and economics of electrical generation. The improvements of these large-scale generation plants were critical to the process of centralised generation, as they would become vital to the entire power systems used today. Alternator means the engine drives the generator's rotor.

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An alternator is an electromechanical device that converts mechanical energy to electrical energy 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 primary objective is to drive the rotor using an Internal Combustion Engine (ICE) to generate 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 most significant challenges of our time [2]. There is an increasing need for more capable and intelligent use of energy sources by incorporating enriched design and optimised algorithms to enhance the sustainability of power-generating systems through innovative solutions. In this regard, the method and tools are designed to create a flexible coupling system using waste tyres for power and torque transmission in a generating plant, thereby converting waste into wealth. The design of a flexible coupling made from waste tyres can significantly contribute to addressing the challenge of tyre waste accumulation in the environment. The specific objectives are to design flexible couplings that utilise waste tyre materials for a generating plant and to evaluate the performance of the designed flexible couplings. A design for a flexible coupling for a tyre was developed, capable of transmitting power ranging from 5 to 30 kW from an 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 helpful 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 include bushed pin-type couplings, universal couplings, Oldham couplings, gear couplings, bellows couplings, jaw couplings, diaphragm couplings, and tyre couplings. The flexible coupling type was considered in this study because it is relatively inexpensive and utilises 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:

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- **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 either English or metric units.

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 a significant 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 power ranging from 5 to 30 kW from a variable-speed (1,000-3,000 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 in diameter. Dimensions shown in [10] are considered as basis for the tyre couplings design. The design schematic configuration, which shows the relationship between the engine, the type of couplings, and the alternator, is shown in Fig. 1.

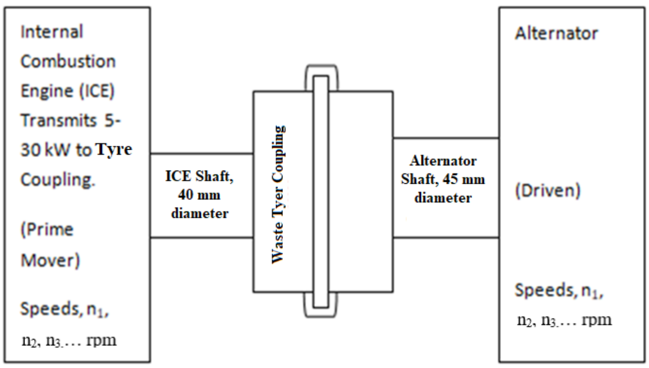

Fig. 1 Relationship between engine, coupling and alternator.

C. Reasons for Tyre Coupling Design Choice

The reasons for the tyre coupling design choice are:

- Waste tyre materials can be put to 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 typically exhibits fire resistance and antistatic properties.
- 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 can cushion against destructive shock loads, protecting the entire system, preventing unexpected breakdowns, and thereby sustaining machine life.
- It is free of backlash and does not create a snatch on the take-up of the drive.
- It is easy to install and requires only simple tools and basic skills during the installation process. 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 engines (ICEs), which increase with ICE speed.
- The tyre is easily removable and replaceable.
- It is helpful in an 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 the 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].
- Based on (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 the required bores [10].
- Design dimensions for the standard couplings, F, H and/or B types are given by [10].

F. Tyre Coupling Design

About 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 connect 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

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[10].
Hence, the service factor is 1.5.

- Design Power (DP): Based on Section E, the Design Power (DP) was calculated using the Normal Running Power (NRP) and Service Factor (SF), as shown in Eqn. 1, and the results were compared to the standards.

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

Table 1 shows the results obtained for Design Power, varying Normal Running Power in steps 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 from 1000 rpm to 3000 rpm in steps 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 coupling's 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: Concerning [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 to withstand the running speed of the engine (1000- 3000 rpm). The maximum allowable speeds of the engine at each power rating are given in Table 4.

G. Performance Evaluation

Performance Evaluation was carried out using a modified F60 flexible coupling standard, which has a power rating of 7.5 kW. Waste tyres, hubs, flanges, keys and keyways, bolts, nuts, and other critical components were made to follow the standard dimensions of F 60 Flexible Company. The acceptable specifications of the F60 design were used for the test. 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 demonstrated that a service factor of 1.5 was sufficient for all categories of power ratings, which ranged from 7.5 kW to 45 kW. This corresponds to a minimum of sixteen (16) running hours of an internal combustion engine. The selected power ratings and standard coupling sizes, varying ICE speeds from 1000 rpm to 3000 rpm in increments 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 of 7.5 kW was 11.10 kW. This enabled the selection of the optimal coupling size, F60.

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Similarly, at a speed of 1000 rpm and a design power of 7.5 kW, for example, it was revealed that both shaft diameters (ICE and Alternator) within the specified range (40-45 mm) fell within the available bore range (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 powered the generating plant, as shown in Fig. 2. The standard physical characteristics of the waste tyre couplings, namely torque, torsional stiffness, and maximum allowable misalignment, were met, and they were able to withstand the maximum permissible speeds of the engine at each power rating.

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 litter our environment by finding a critical industrial and mechanical area where these wastes can be put to 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 a 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 the best choice of power ratings varied with the speeds of the internal combustion engine and was 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.
- F60 tyre couplings can be modified using waste tyres and can perform adequately in transmitting powers/torques from the engine to the alternator, provided that all standard dimensions are met.

From this study, the following recommendation can be made:

- The use of waste truck tyres is commendable for making flexible couplings locally. This will promote localization of industries.
- The use of flexible couplings in generating plants 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 the power ratings of the installed coupling to avoid failure.
- F60 tyre couplings were recommended for the adoption of waste tyres because of their 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 comparing them to the standards.

DECLARATION

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Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	B. Kareem designed and was involved in ensuring the technical accuracy of the work. A.S. Lawal conducted the literature review and manuscript drafting, while S. Drisu carried out the experiment and the initial drafting.

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