Flexible Couplings Design Management System for Generating Plants

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ABSTRACT

This study has provided a computer programming method of solving the problem of quick design and selection of tyre flexible couplings applied in power generating plants. First, a theoretical design model was developed for tyre flexible couplings by relating transmission power of the couplings to the power ratings and the service factor of generating plant. On this basis, standard coupling sizes, and dimensions were selected at varying speeds, 1000, 2000 and 3000 rpm, from which the best choice of waste tyre coupling was made. Computer software package was developed using python language for robust and quick selection of the best coupling sign for a given power ratings of the generating plant. A case study results showed that for over 16 hours of running the generating plant, the selected service factor (1.5), engine speed (1000 rpm), coupling size (F 60), bore diameters (42-48 mm) and power rating (11.10 kW) performed satisfactorily. Couplings selection results of the five cases obtained from the computer package were consistent with the ones obtained manually. Computer package performed better with time saving of more than 99%. Therefore the system is capable of selecting the best tyre flexible couplings for a given generating plant power operated within the stated (16) hours without recourse to manual design and flexible coupling standards.

Keywords: Tyre Flexible Couplings, Management System, Generating Plant, Design.

INTRODUCTION

The power generation is the backbone of every country to survive in this world. Electricity generation is the process of generating electrical power from other sources of primary energy. The fundamental principles of electricity generation were discovered in the 1820s and early 1830s by British scientist Michael Faraday (Faraday, 1991). His method, still used today, is for electricity to be generated by the movement of a loop of wire, or Faraday disc, between the poles of a magnet. 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 mechanical production of electric power began the Second Industrial Revolution and made possible several inventions using electricity, with the major contributors being Thomas Alva Edison and Nikola Tesla. Previously the only way to produce electricity was by chemical reactions or using battery cell and the only practical use of electricity was for the telegraph.

Electricity generation at central power stations started in 1882, when a steam engine driving a dynamo at Pearl Street Station produced a DC current that powered public lighting on Pearl Street, New York. The new technology was quickly adopted by many cities around the world, which adapted their gas-fueled street lights to electric power. After these, electric lights were used in public buildings, in businesses, and to power public transport, such as trams and trains (Kareem et al, 2012; Kareem et al., 2018).

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

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sources (Oputa 2016).

In the 1880s the popularity of electricity grew massively with the introduction of the Incandescent light bulb. Although there are 22 recognized inventors of the light bulb prior to Joseph Swan and Thomas Edison, Edison and Swan's invention became by far the most successful and popular of all. During the early years of the 19th century, massive jumps in electrical sciences were made. And by the later 19th century the advancement of electrical technology and engineering led to electricity being part of everyday life. With the introduction of many electrical inventions and their implementation into everyday life, the demand for electricity within homes grew dramatically. With this increase in demand, the potential for profit was seen by many entrepreneurs who began investing into electrical systems to eventually create the first electricity public utilities. This process in history is often described as electrification.

The earliest distribution of electricity came from companies operating independently of one another. A consumer would purchase electricity from a producer, and the producer would distribute it through their own power grid. As technology improved so did the productivity and efficiency of its generation. Inventions such as the steam turbine had a massive impact on the efficiency of electrical generation but also the economics of generation as well (Ohajianya et. al., 2014). This conversion of heat energy into mechanical work was similar to that of steam engines, however at a significantly larger scale and far more productively. 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 system that we now use today (Kumpel, 2012).

Throughout the middle of the 20th century many utilities began merging their distribution networks due to economic and efficiency benefits. Along with the invention of long-distance power transmission, the coordination of power plants began to form. This system was then secured by regional system operators to ensure stability and reliability. The electrification of homes began in Northern Europe and in the Northern America in the 1920s in large cities and urban areas. It wasn't until the 1930s that rural areas saw the large-scale establishment of electrification.

Alternator means generator’s rotor drive or move by engine. An alternator is an electromechanical device that converts mechanical energy to electrical in the form of alternating current (Kareem et al., 2012). 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. The main aim is to move and drive the rotor by a generator to produce 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 (Kareem, 2018; Uhunmwagho and Kenneth, 2013). Thus, 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 (Istrail et al., 2015). 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.

The main solution to the problem of waste tyres that littering our environment is to find how best these wastes can be used to make useful components for industrial applications. Design of a flexible coupling made of waste tyres can go a long way in addressing these challenges of tyre wastes accumulation in the environment.

In this study a computer program for the design of tyre flexible coupling was developed for application in power generating plants. The designed flexible coupling will be capable of transmitting 5-30 kW power within a speed range of 1000- 3000 rpm. Computer program in Python language was developed to implement the design. Python language was applied due to its flexibility, user friendliness and familiarization.

LITERATURE REVIEW

A coupling is a device that connects two shafts for the transmission of power (DC, 2023). According to the alignment accuracy and torque required, couplings can be rigid or flexible (AGMA, 2023). Flexible couplings are types of couplings connect two shafts that are misaligned both laterally and angularly (FC, 2023). This can be found in motors, pumps, generators, and compressors, among other things. Overload protection is also provided in flexible coupling during power transmission (HUCO, 2023). A few examples are bushed pin-type couplings, universal couplings, Oldham couplings, gear couplings, bellow couplings, jaw couplings, diaphragm couplings and typre couplings (Globalspect, 2023).

The related empirical studies are given thus. Zhang et. al. (2022), researched on the design of flange coupling system with uniform strength bolts in order to depict a way to reduce the stress that acting on the bolts by making it uniformly strengthen. The stress in the threaded part of the bolt will be higher than that in the shank. Hence a greater portion of the will be absorbed at the region of the threaded part which may fracture the threaded portion because of its small length. An axial hole is drilled at the centre of the bolt through the head as far as thread portion such that the stress in the bolt is uniformly distributed along the length of the bolt. Also, failure analysis of a universal joint flange coupling of an automobile power transmission system was carried out by Babu et al. (2017). Spectroscopic analyses, metallographic analyses and hardness measurements are carried out for each part. For the determination of stress conditions at the failed section, stress analysis is also carried out by the finite element method. The common failure types in automobiles and revealed that the failures in the transmission system elements cover 1/4 of all the automobile failures. The failure is analyzed in the ANASYS with FEM.

Kishor and Raghu, (2014) researched on keyless coupling. The device provides an ultimate solution by incorporating all the advantages of interference fits, while eliminating mounting and removal problems. Analysis is carried using ANSYS. The obtained results are compared with standard values. The standard values are taken for RINGFEDER catalog. The keyless data is taken from RINGFEDER. Here it has made an attempt in analyzing keyless coupling. From the results it can be concluded that keyless coupling is most suitable. Key and keyless coupling are modeled and simulated using FEA approach (Yadav and Sharma, 2019). By using ANSYS software. Nonlinear analysis is carried out with appropriate material constant. Using FEA stress and pressure are obtained for different bolt load. In key coupling power transmitting is 24.4 KW at 100 rpm, the stress concentration in shaft is 49.25 N/mm^2. For fluctuating load this cause a crack initiation at the stress concentration point. In this case the same power is transmitted with lesser diameter by keyless coupling. The keyless coupling is operated at same power 24.4 KW and speed is 200 rpm. The obtained torque values are compared with standard torque. In design variant 6 obtained torque value 1807696.9 N-mm is nearer to standard value 1839967.3 N-mm. Keyless coupling is more suitable compared to key coupling, and diameter of the shaft can be reduced. It provides completely tight fit around shaft no backlash. It can transmit high torque and axial loads. In keyless coupling it can transfer more power when compare to key coupling.

Raj and Ibhiram (2019), presented the development of a program code for the protected type flange coupling in an Object-Oriented Programming (OOP) language like “PYTHON”, which takes input (like required power input, no of rotations and desired factor of safety etc.) from designers, and then accordingly calculates the specifications of the coupling using design standard formulas and iterative procedures until the design meets the safe criteria. The final specifications are displayed along with the list of recommended materials for the coupling based on the design. The main objective of the paper is to write a generalized python program for the design of protected type flange couplings for any selected material considering all the design parameters. The activity tends to lead the manufacturing operations towards a more time-efficient, cost-effective and a more reliable and an optimized way of designing machine elements and aims to give better clarity to shop floor workers. Presently, the Oldham’s coupling and Universal joints are used for parallel offset power transmission and angular offset transmission. These joints have limitations on maximum offset distance, angle, speed and result in vibrations, noise and low efficiency (below 70%). These limitations can be overcome with Thompson constant velocity (CV) coupling which offers features like minimizing side loads, higher misalignment capabilities, more operating speeds, improved efficiency of transmission and many more. The constant velocity joint is an alteration in design that offers up to 18 mm parallel offset and 21-degree angular offset, at high speeds up to 2000 or 2500 rpm at 90% efficiency. The constant velocity coupling design lowers cost of production, space requirement and simply technology of manufacture (Moghe*et. al*, 2017).

Maurya *et. al*., (2019), compared the result obtained from theoretical calculation and finite element (FE)

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analysis of rigid flange coupling. The coupling is used in chemical industry where it is installed in screw conveyer having high torque and slow speed. The material from which coupling is manufacture is EN8 as it has better properties than most of the material from which coupling is manufactured like mild steel, cast iron. The theoretical calculation is done using input data parameters and used to prepare CAD (Computer Aided Design) model using SolidWorks15. Finite element analysis is done using sophisticated FE analysis software workbench 18.1. The result obtained from both the theoretical calculation and finite element analysis is compared to check design is safe against shear failure or not. In essence, considering the literature survey presented, research work is needed to be intensified in the aspect of establishing coupling designs for various loads of generator set. This will aid the selection of coupling types and their developments for power generating sets.

From the above discussion on the various connection mechanisms of the mechanical power transmission, by considering the cost of material and expensive nature of many connection/coupling systems, it was found that flexible couplings are adaptable to the use of tyre material for their production. Hence, in this design, waste tyre products (Heavy Duty truck/equipment tyres) as the source of transmission which is more economical, durable and easily available. Besides, there are scanty studies on the development of computer programming for the choice and selection of best flexible coupling design for a given transmission power rating of generating plant. These caps are filled by this study.

RESEARCH METHODOLOGY

The purpose of a flexible coupling is to transmit torque from one piece of rotating equipment to another, while accepting at the same time a small amount of misalignment (FC, 2023).

Design of 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 per day was carried out. The engine shaft is 40mm and the alternator (rotor) shaft is 45 mm diameter. Flexible coupling standard dimensions shown in Fenner (2023) standard were considered as basis for the design. The design schematic configuration that shows the relationship between the engine, the type couplings and the alternator is shown in Fig. 1.

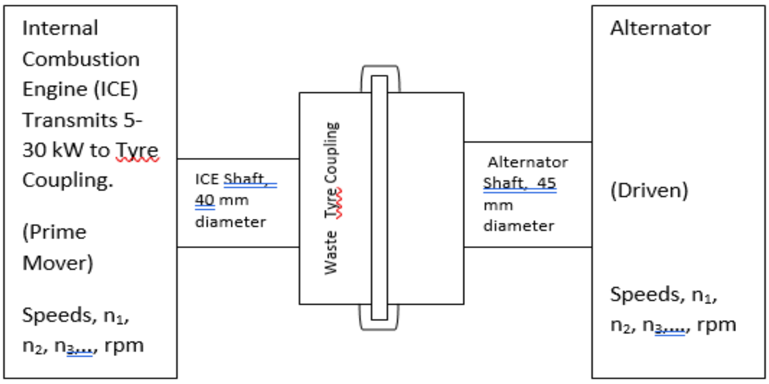

Fig. 1. Tyre flexible coupling system for generating plant

The properties of waste tyre and design requirements (Fenner, 2023) informed its suitability for its application in flexible couplings for power transmission which formed the basis of this design.

The following steps were followed in flexible tyre coupling design.

i. Required service factors are determined based on the class of driver and driven systems. This was selected based on flexible tyre coupling design standards.
ii. Computation of tyre coupling design power by multiplying the normal running power by the service factor. The design power obtained formed the basis for selecting the standard coupling.
iii. On the basis of (ii), coupling sizes were obtained by reading across from the appropriate speeds until a power greater than that required in (ii) was found (Fenner, 2023, Standard) .
iv. The sizes of tyre couplings required were found at the head of that column.

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v. Dimension tables were checked for the chosen flanges to accommodate required bores.
vi. Design dimensions for the standard couplings, F, H and B types are given (Fenner, 2023).

The stated design steps (i-vi) were applied as follows:

i. 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. Hence, service factor is 1.5 (Fenner, 2023).

ii. Design Power (DP): The Design Power (DP) was computed based on Normal Running Power (NRP) and Service Factor (SF) as

$$DP=NRPxSF \qquad (1)$$

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) (Table 1). For instance, the first step;

$$DP=5kWx1.5=7.5kW \qquad (2)$$

iii. 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 the standard table (Fenner, 2023). 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 the standard table, the first figure to exceed the required power 7.5 kW in step (ii) is 11.10 kW (Fenner, 2023). The size of the coupling is F 60.

iv. Bore Sizes: With reference to Fenner standard, 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).

v. Standard design dimensions were also obtained for the selected coupling types (F & H) as shown in Fenner, 2023 standard table.

vi. The selected couplings were designed so as to withstand the running speed of the engine (1000- 3000 rpm).

The developed algorithm/flowchart for the model was programmed using Python Computer programming language. Python language was chosen due to its user-friendliness, and capability of solving the design problem. The steps of implementing the design program are as follows.

i. Welcome page which is the starting page of the design is shown in figure 2; figure 3 presents design parameter input interface; figure 4 represents design sample parameter input value page of the Tyre Flexible Couplings Design Software (TFCDS 1.0); while figure 5 displayed output results.

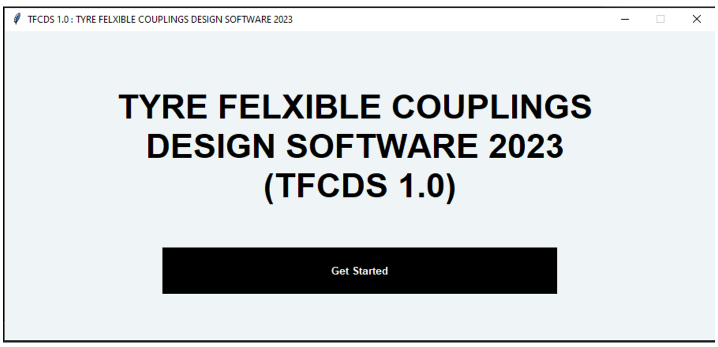

Fig. 2. Welcome page of the TFCDS 1.0 software

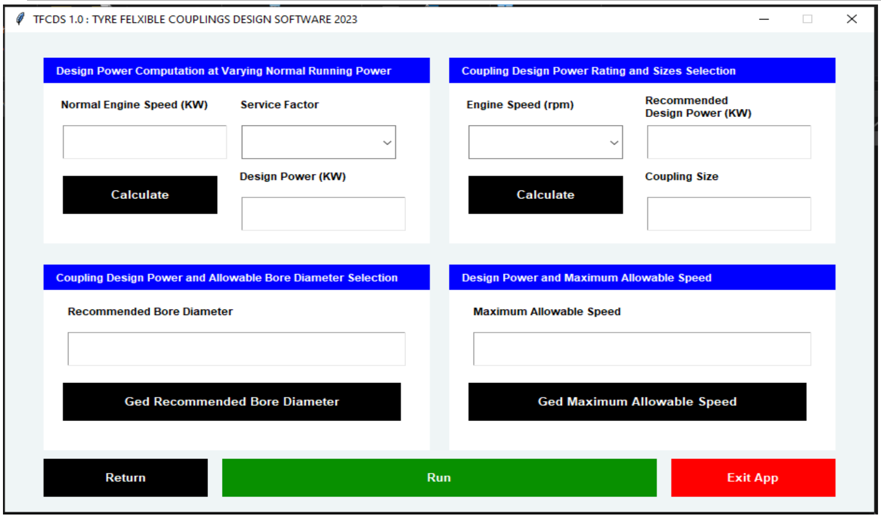

Fig. 3. Empty input value page of the TFCDS 1.0 software

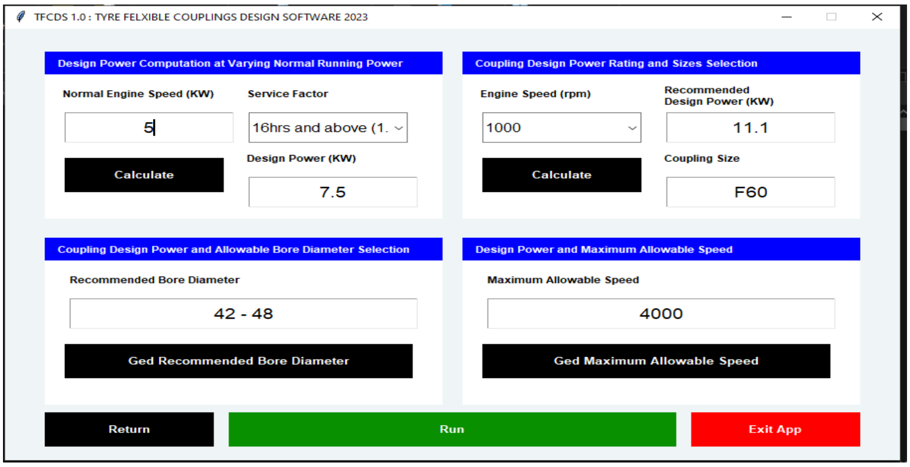

Fig. 4. Sample input value page of the TFCDS 1.0 software

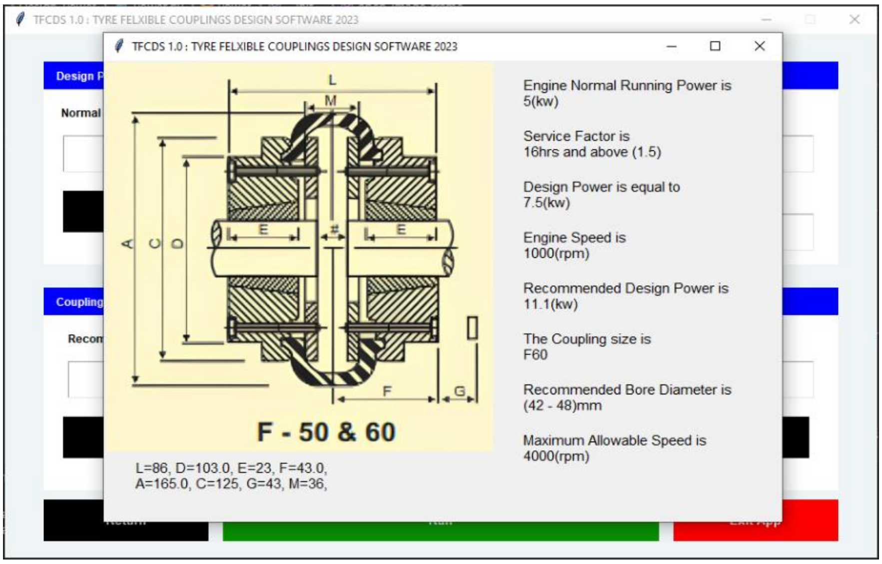

Fig. 5. Displayed Answer page of the TFCDS 1.0 software

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. Other designs of tyre flexible couplings for generating plants of power ratings range between 5-30kW were carried out using computer software package developed.

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.

Table 1. Computation of Design Power 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

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.

Table 2. Couplings Standard Design Sizes and Power Ratings Selection at Varying Speeds

Design Power (kW)/ Speed (rpm)	1000 rpm	2000 rpm	3000 rpm
7.5	F 60 11.10	F 45 7.80	F 45 11.00
15.0	F 70 17.0	F 60 22.20	F 50 16.70
22.5	F 80 26.50	F 70 33.90	F 60 33.30
30.0	F 85 32.0	F 70 33.90	F 60 33.30
37.5	F 90 38.20	F 80 53.00	F 70 50.90
45.0	F 100 52.90	F 80 53.00	F 70 50.90

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 bolded in Table 3. Hence, the selected bore range is adequate to fit the shafts of the engine and alternator.

Table 3. Design Power and Allowable Bore Diameter Selection for the Shafts

Design Power (kW)/ Bore (mm)	Max. diameter of driver shaft (IC Engine) 40 mm Max. diameter of driven shaft (Alternator) 45 mm		
	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

Performance evaluation showed that tyre couplings designed using standard design dimensions (Fenner, 2023) were adequate for the given generating plants power ratings by applying both manual and computer software package developed with latter approach provided a faster computation time than the former. Also, the tyre couplings designed were capable to withstand the maximum allowable speeds (1000-3000rpm) of the engine at each of power ratings (Table 4).

Table 4. Design Power and Maximum Allowable Speeds

Design power (kW)	Revolution (rpm)		
	1000	2000	3000
7.5	F 60, 4000	F 45, 4500	F 45, 4500
15.0	F 70, 3600	F 60,4000	F 50,4500
22.5	F 80, 3100	F 70, 3600	F 60, 4000
30.0	F 85, 3000	F 70, 3600	F 60, 4000
37.5	F 90, 2880	F 80, 3100	F 70, 3600
45.0	F 100, 2600	F 80, 3100	F 70, 3600

CONCLUSION

This study has provided a method that enable robust tyre couplings design for generating plants of variable power ratings. This has given the opportunity of converting waste truck tyres that are littering our environment into a wide range of productive uses. In this study, a computer programming that enabled a robust design of tyre flexible coupling was developed and its performance was measured by comparing its outcomes with manually designed ones in terms of value and efficiency. Finally, the study has produced a computer software package for the design of tyre flexible couplings for power generating plants of different capacities. This has enabled efficient and accurate choice of tyre couplings for generating plant based on its capacity as compared to time-wasting random selection approach of the past. Further conclusions that can be drawn from the results are as follows:

i. The designed flexible couplings using waste tyres were capable of transmitting power/torque from the generating plant for over 16 hours without failure.

ii. 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.

iii. It was revealed that best choice of power ratings varied with the speeds of internal combustion engine and higher than estimated coupling power ratings.

iv. In design cases considered, the standard bores of the couplings fell within the available shaft diameters of the engine and the alternator.

v. It was established that waste tyre couplings designed using standard design dimensions were adequate in powering generating plants of varying power ratings.

vi. The design values based manual and computer evaluation were similar. This has shown that the computer software developed can adequately adopted for effective design and selection of best coupling standard sizes at a given power ratings of the generating plant. The computer software package approach is efficient by enabling time savings of more than 99% as compared to manual design.

vii. The design software will enable the application of waste truck tyres in production of flexible couplings, and at the same time encourage the use of flexible coupling in transmitting power on generating plants locally. This will promote localization of industries.

viii. Further study is recommended in the area of design for integrity of the coupling materials involved and compare them to the standards.

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