Design Of Freewheel Coupling

by

Mohd Taufek Bin Tumali

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JANUARY 2008

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Design Of Freewheel Coupling

by

Mohd Taufek Bin Tumali

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____

(Miss How Meng Git)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2008

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MOHD TAUFEK TUMALI

ABSTRACT

Generator is a machine in which mechanical energy is converted to electrical energy. Generators are made in a wide range of sizes, from very small machines with a few watts of power output to very large central-station generators providing 1000 MW or more [1].

Within a generator set, there is a radiator connected to the engine, by means of coupling. Commonly, fixed couplings are used which could create a damaging high torsional effect. The objective of this project is to design and develop a freewheel coupling that can overcome the problems mentioned.

The scope of study includes designing the new coupling, the fabrications and the improvement of the existed coupling used. There are many works that need to be carried out especially in designing and fabricating. It involves researches, software skills especially AUTOCAD, purchasing raw material, skills on using related machines for fabrication part and many more.

At the end of the project, a prototype of a new design of coupling should be made. All the information that related to the design and anything involved during the process to complete the project will be compiled in a final report. This project will benefit the most to the packager since it can reduce the cost since they do not have to import the coupling from oversea. Because of that, they can propose lower price of a generator set in their bidding process. The other option is they still can maintain the same price, then the packager can gain more profit in their project. It will also benefit the end user or the clients since they can buy a generator set not only with lower price, but also with improved design which overcome the problem stated above.

ACKNOWLEDGEMENT

First and foremost, the first and highest gratitude goes to God because of His mercy and kindness that I have successfully completed this project within the time provided.

I would like to express my special gratitude to my FYP supervisor, Miss How Meng Git for giving me an opportunity to learn a lot of knowledgeable experiences throughout this project. I again would like to extend my thanks and deep appreciation to her, whose guidance and advice had helped me a great deal in completing this project.

I gratefully acknowledge the assistance and guidance from the Manufacturing Laboratory Technician, Mr Mohd Jani Awang and Mr. Zamil for their helpful advices during the project execution, especially in matters regarding the practical usage of equipments in the laboratory such as EDM Wirecut, Welding, Lathe, Milling, Linear Hacksaw and Hydraulic Shearing Machines.

I also would like to thank Mr Rohizat from SG Power System Sdn Bhd for helping me out to figure out the problem regarding this project title.

Among other people that had indirectly involved in project development process is a small core of individuals who deserve special praise and recognition. I owe my deepest appreciation to my parents and siblings for their endless encouragement and support. I also thank friends, especially Miss Faerah Nasir who believed in and constantly supported the work throughout the semester.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study [1]

A diesel generator (Figure 1) is the combination of a diesel engine with an electrical generator (often called an alternator) to generate electric energy.

Diesel generators are used in places without connection to the power grid or as emergency power-supply if the grid fails. Small portable diesel generators range from about 0.8kW to 8kW, while the larger industrial generators can range from 6.4kW – 24kW for homes, small shops & offices up to 1600kW used for large office complexes, factories and power stations. These generators are widely used not only for emergency power, but also many have a secondary function for providing back up power to utility grids.

Figure 1: Generator set

Ships often also employ diesel generators, sometimes not only to provide energy for electric systems, but also for propulsion. The use of diesel generators for propulsion is actually becoming more common due to the fact that in this arrangement the generators do not need to be close to the propeller and instead they can be placed in better positions, usually allowing more cargo to be carried. Such a diesel-electric arrangement is also used in some very large land vehicles.

1.2 Problem statement

Big radiators use large fan blades. By using fixed coupling (Figure 2), it will cause a sudden stop of large fan blade which will create a high torsional effect onto the bolting and the crank shaft Power Transmitted Output (PTO) end. This effect will cause the bolting to fail and also will create a twisting effect on the PTO end. It is very undesirable for big diesel engine. It will also create impact to the blade which it will cause the blade to snap.

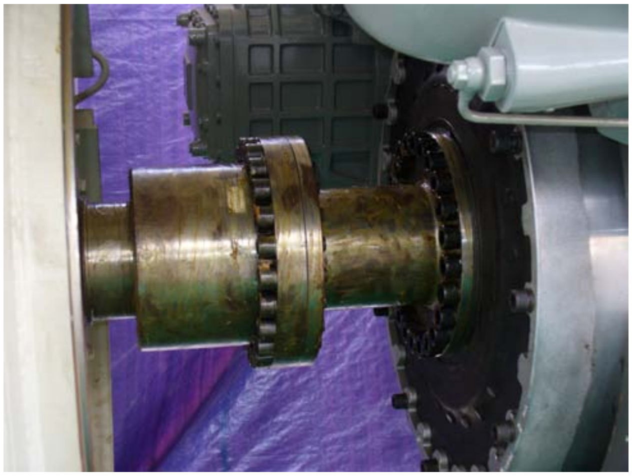

Figure 2: Coupling

1.3 Objectives and Scope of Study

1.3.1 Objective

The objective of this project is to design a freewheel coupling which allows the radiator fan stop by itself when the engine stop. The design is believed to have very big potential in market since it overcome those problems stated and there are no local producer yet for such coupling design.

1.3.2 Scope of study

a) Literature review

- Brief study on function of generator set and its main component.
- Study on how coupling actually works so that any modification to the design would not affect its main function.
- To find and study the fundamental calculation in the design of coupling.
- Researches and study on similar coupling types.

b) Designing

- To design and research for various types of mechanical designs of freewheel coupling.
- To study any type of mechanism on existing designs as references.
- To do researches on finding the best material that can be used for the design.
- To do the cost analysis for the whole project considering all issues such as fabrication, buying raw material, process, and many more.

c) Fabrication

- To cut the raw material into specified dimension based on the design.
- To assemble and install all the components.

d) Design validation

- Validation of the design to determine the achievement of project objective

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

2.1 Working Principle of Generator Set [2]

Compressing any gas raises its temperature, this is the method by which fuel is ignited in diesel engines. Air is drawn into the cylinders and is compressed by the pistons at compression ratios as high as 25:1, much higher than used for spark-ignite engines. Near the end of the compression stroke, diesel fuel is injected into the combustion chamber through an injector (or atomizer). The fuel ignites from contact with the air that, due to compression, has been heated to a temperature of about 700–900 °C (1300–1650 °F). The resulting combustion causes increased heat and expansion in the cylinder which increases pressure and moves the piston downward. A connecting rod transmits this motion to a crankshaft to convert linear motion to rotary motion for use as power in rotating the alternator shaft to generate electricity. Intake air to the engine is usually controlled by mechanical valves in the cylinder head. For increased power output, most modern diesel engines are equipped with a turbocharger, and in some derivatives, a supercharger to increase intake air volume. Use of an aftercooler/intercooler to cool intake air that has been compressed, and thus heated, by the turbocharger increases the density of the air and typically leads to power and efficiency improvements.

An alternator is an electromechanical device that converts mechanical energy to alternating current electrical energy. The alternator generates electricity by the same principle as DC generators, namely, when the magnetic field around a conductor changes, a current is induced in the conductor. Typically, a rotating magnet called the rotor turns within a stationary set of conductors wound in coils on an iron core, called the stator. The field cuts across the conductors, generating an electrical current, as the mechanical input by the engine causes the rotor to turn.

2.2 Coupling [2]

Coupling is a constant torque device for joining shaft end to end in such a manner that continuous rotary motion of the drive shaft in one direction causes continuous rotary motion of the driven shaft in the same direction with no reduction in torque and little if any reduction of speed. No limitation on speed is usually imposed, but careful aligning of shaft is required. Couplings are fairly permanent shaft connections in which they are permanent until servicing or rebuilding becomes necessary. Couplings differ widely in size and appearance. However, nearly all coupling consist of 3 basic members which are 2 shaft hubs and a connector or connecting element.

A coupling usually must accomplish several objectives in addition to transmitting rotary power. These include allowing or compensating for misalignment between the rotating coupled shafts and allowing axial or end movement of the coupled shafts. Some couplings also provide a means of damping vibration and insulating the coupling halves from electrical current transfer. Coupling are also produced that perform added special jobs such as preventing shaft overload, acting as a brake, or allowing the driver and driven parts to be spaced some distance apart. Such compound designs save space and reduce cost.

Couplings are different for machine systems because power units and driven machines are often manufactured separately instead of as a unit. Within a machine system couplings may also provide convenient drives for auxiliary equipment. During repair or testing, couplings facilitate temporary disconnection of machine components to permit one member to rotate while the other is stationary. This is often a safety feature.

2.3 Selection of a type of coupling of a shaft with a hub [4]

The following comparisons of basic properties of individual types of coupling may be helpful for a simpler selection of the type of coupling of a shaft with a hub. When selecting the design of the coupling, it is necessary to take into account its utility, time demands and financial costs of the design, production, assembly and disassembly of the coupling.

2.3.1 Shaped couplings [4]

Shaped couplings (Figure 3) of shafts with hubs are designed only for transfers of torsional moments. The transfer of external loading is ensured with these couplings using matching profiles of the shaft and hub (splined shafts, polygonal couplings) or inserted elements (pins, keys, wedges). Shaped couplings are loaded for deformation, shear and possibly for bend. For dimensioning of the coupling, only a check for deformation is usually authoritative and sufficient. Unlike friction couplings, there does not appear any additional stress in the hub here due to prestressing of the coupling. However, a considerable notch effect of holes and splines on the shaft is a disadvantage of this design. Therefore, it is necessary to check these shafts for shape strength.

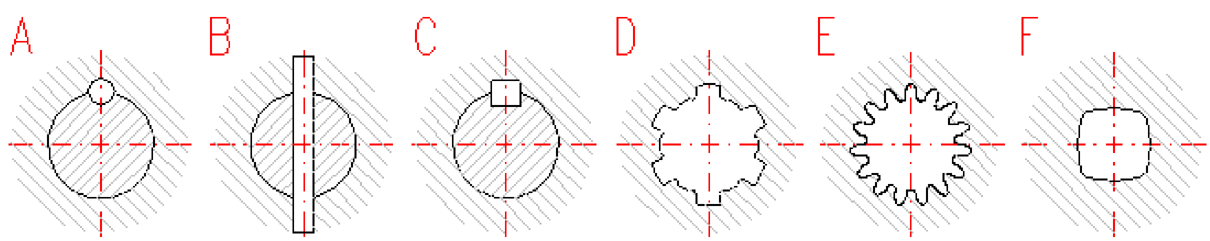

Figure 3: Types of shaped coupling

A. Couplings with longitudinal (joint) pin
B. Couplings with cross pin
C. Couplings with keys
D. Couplings with straight-sided splines

2.3.2 Power (friction) couplings [4]

Power couplings (Figure 4) of shafts with hubs allow transfer of axial forces in addition to torsional moments. External loading in these coupling is transferred using friction between the shaft and hub, which appears in the coupling during its assembly. In case of clamping couplings and couplings with clamping rings, the friction in the coupling is caused by normal forces caused by bolts, hoops, conical surfaces or tapered rings. In case of pressure (pressed on) couplings the friction is caused by normal internal forces caused by elastic deformations of the coupled parts. In the course of assembly of the coupled parts, there appears pressure that must not exceed the permitted value. Smooth and non-weakened section of the shaft and options of very fine adjustment of the mutual position (turning) of the coupled parts are advantages when compared with shaped couplings.

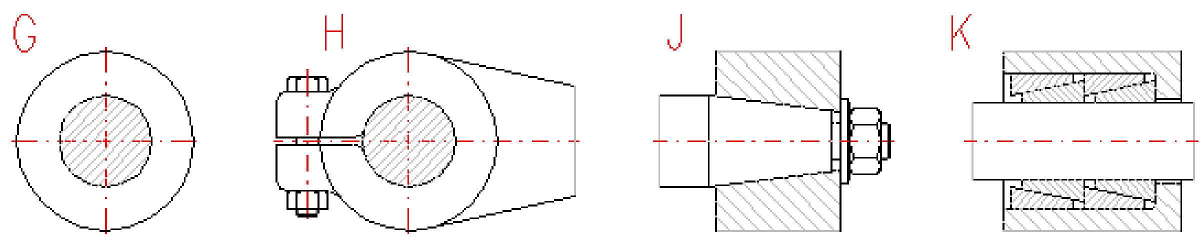

Figure 4: Commonly used power coupling

G. Pressed on couplings

H. Clamping couplings with cylindrical surfaces

I. Clamping couplings with conical surfaces

J. Couplings with clamping (distance) rings

Table 1: Utility properties of the coupling [4]

Type of coupling	Use, operation, maintenance and repair of the coupling	Production and assembly of the coupling
Pin couplings	For transfer of small, shock-free and non-cyclical torsional moments The ability of the coupling to be disassembled must be ensured using a suitable design Holes for cross pins have very adverse notch effects.	Very simple production During assembly it is necessary to prevent release Suitable for piece and lot production as well
Couplings using keys and wedges	Only for transfer of torsional moments Suitable for fixed couplings, less suitable for sliding couplings Unsuitable for cyclical torsional moments Centrical bearing of the hub Reliability against fatigue breaks affected adversely by notch effects of the groove Easy disassembly of the coupling	Production of grooves requires the use of special tools Easy assembly of the coupling In case of fixed couplings, it is necessary to prevent axial shifts Suitable for piece production, less suitable for lot production
Splined couplings	Only for transfer of torsional moments Suitable for high loading, cyclical and shock loading Suitable for fixed and sliding couplings as well Ensuring co-axiality and perpendicularity of the coupling is not easy	Production requires special machine equipment Easy assembly of the coupling In case of fixed couplings, it is necessary to prevent axial shift
Polygonal couplings	Only for transfer of torsional moments Suitable for high and cyclical loading at high speed of rotation Suitable for fixed and sliding couplings as well.	Production requires special grinding machines Easy assembly of the coupling In case of fixed couplings, it is necessary to prevent axial shift

Table 2: Time required for design, production, assembly and disassembly of the coupling [4]

Type of coupling	**Production and assembly of the coupling**	**Disassembly of the coupling**
Pin couplings	Very fast production and assembly of the coupling	Depends on the constructional design of the coupling
Couplings using keys and wedges	Relatively slow production without special equipment Fast assembly of the coupling	Fast
Splined couplings	Relatively fast production only with the use of suitable equipment Fast assembly of the coupling	Fast
Polygonal couplings	Relatively fast production only with the use of suitable equipment Fast assembly of the coupling	Fast
Pressed on couplings	Fast production and assembly of the coupling	Unsuitable for fast repairs and disassembly
Clamping couplings	Fast production and assembly of the coupling	Fast

Table 3: Costs for production, operation, assembly and disassembly of the coupling [4]

Type of coupling	Production costs	Costs for disassembly of the coupling
Pin connections	Low	Minimum
Couplings with keys and wedges	Medium	Minimum
Splined couplings	High (economical only in case of lot production)	Minimum
Polygonal couplings	High (economical only in case of lot production	Minimum
Pressed on couplings	Medium	Considerable (sometimes even impossible)
Clamping couplings	Relatively small	Minimum
Couplings using clamping rings	Medium (can be reduced by purchasing finished rings)	Minimum

2.4 Fundamental Calculation in Coupling Design

Referring to Couplings and Joints, Design, Selection, and Application book [5], the following design equation and parameters are required to design a coupling.

2.4.1 Coupling ratings

<u>1) Torque Ratings</u>

Factor of safety are used in the design of a coupling. Coupling designers use factors of safety because there are uncertainties in the design. The designer's method of analysis uses approximations to model the loading, and therefore the calculated stresses may not be exact. Likewise, material properties such as modulus, ultimate strength, and fatigue strength have associated tolerances that must be considered. Generally, torque is the most significant contributor of load to the overall stress picture. The fatigue factor of safety of a flexible element coupling is generally not as affected by torque, because the failure mode in these couplings is not very sensitive to torque during continuous operation.

A *service factor* is used to account for the higher operating torque conditions of the equipment to which the coupling is connected. A service factor could be applied to the normal operating torque of, for instance, a turbine or compressor. This factor accounts for torque loads that are not normal but may be encountered continuously, such as low-temperature driver output, compressor fouling, or possible vibratory torques. Service factors are also sometimes used to account for the real operating conditions, which may be 5-20% above the equipment rating.

<u>2) Design and Selection Criteria Terms</u>

A factor of safety (F.S) is used to cover uncertainties in a coupling design-analytical assumption in stress analysis, material unknowns, manufacturing tolerances, etc. under given design conditions the FS is the ratio of strength (or stress capacity) to predicted stress, where the stress is a function of torque, speed, misalignment, and axial displacement.

The *endurance limit* is the failure strength limit of a coupling component subjected to a combination of constant and alternating stresses. Beyond this limt the material can be expected to fail after some finite number of cycle loads. Below this limit the material can be expected to have infinite life (factor of safety greater than 1.0)

The *yield limit* (Y.L) is determined by the manufacturer to be the failure strength limit of a coupling component that will cause damage. If this limit is exceeded, the coupling should be replaced.

The *maximum continuous rating* (M.C.R) is determined to be the torque capacity at which a coupling can safely run continuously and have a acceptable design factor of safety.

The *peak rating* (P.R) is determined to be the torque capacity that a coupling can handle without experiencing localized yielding of any of its components. Additionally, a coupling can handle this torque condition for 5000-10000 cycles without failing.

The *maximum momentary rating* (M.M.R) is determined to be the torque capacity that a coupling can experience without ultimate failure although localized yielding (damage) of one of its component may occur. A coupling can with stand this occurrence once for a brief time. After that, the coupling should be inspected and possibly replaced.

3) Speed Ratings

Maximum Speed Based on Centrifugal Stress.

The simplest method of establishing a coupling maximum speed rating is to base it on centrifugal stress (S_t):

Centrifugal stress, $S_t = \rho V^2/g$

Where ρ = density of material (lb/in^3)

V = velocity (in./sec)

g = acceleration (386in./sec)

$$\text{Velocity, } V = D_o \times \pi \times rpm / 60$$

$$\text{Revolution per minute, } rpm = 375\sqrt{(S_t/\rho)} / D_o$$

Where D_o = outside diameter (in.)

$$S_t = S_{yld} / F.S$$

Where, F.S = factor of safety (can be 1-2, typically 1.5)

S_{yld} = yield strength of the material (psi)

2.4.2 Coupling Component Strength Limits

<u>Allowable Limits</u>

Depending on the type of loading, the basis for establishing allowable stress limits may vary. Usually, loads can be classified into three groups:

1. Normal or steady state
2. Cyclic or reversing
3. Infrequent or peak

Therefore, for comparison purposes we can conservatively establish three approaches stated above to determine allowable stress limits.

a) Normal Steady State-Loads

$$S_t = S_{yld} / F.S$$

$$\tau = 0.577S_{yld} / F.S$$

Where S_t = allowable tensile stress (psi)

τ = allowable shear stress (psi)

S_{yld} = yield strength (psi)

F.S = factor of safety (1.25-2)

b) Cyclic or Reversing Loads

Where loading produces primarily tensile or shear stress

$$S_{te} = S_{end} / (F.S \times K)$$

$$\tau_e = 0.577S_{end} / (F.S \times K)$$

Where S_{te} = allowable endurance limit of tensile stress (psi)

S_{end} = tensile endurance limit (psi) = 0.5Sult

K = stress concentration factor

τ_e = allowable endurance limit for shear stress (psi)

Factor of safety are 1.25-2, usually 1.5

K usually ranges from 1.25-2

c) Infrequent Peak Loads

In these cases F.S ranges from 1.0 to 1.25 typically 1.1

$S_t = S_{yld} / F.S$

$\tau = 0.577S_{yld} / F.S$

2.4.3 General Equations

The following equations is also needed in order to determine all the stresses involve in coupling design based on "*Machine Design Fundamentals, A Practical Approach*" [3] and "*Couplings and Joints Design, Selection, And Application*" [5] books.

2.4.3.1 Torque

$$\text{Torque } (T) = P\,(9550) / n \ \ (\text{N.m})$$

Where P = Power (kW)

n = speed (rpm)

2.4.3.2 Component Stress Equation

Solid shaft, $\tau_s = 16T / \pi Do^3$

Tubular shaft, $\tau_s = 16TD_o / \pi(D_o^4 - D_i^4)$

Where D_o = outer diameter (mm)

D_i = inner diameter (mm)

T = Torque (N.m)

Key stresses:

$$T = FD_n / 2$$

$$F = 2T / D_n$$

Shear stress, $S_s = F / wL$

$= 2T / WLD_n$

Compressive stress, $S_c = 2F / hL = 4T / hLDn$

Where, L = length of key (m)

n = number of keys

D = shaft diameter (m)

w = key width (m)

h = key height (m)

T = torque (N.m)

F = force (N)

2.4.3.3 Hub stresses and capacities

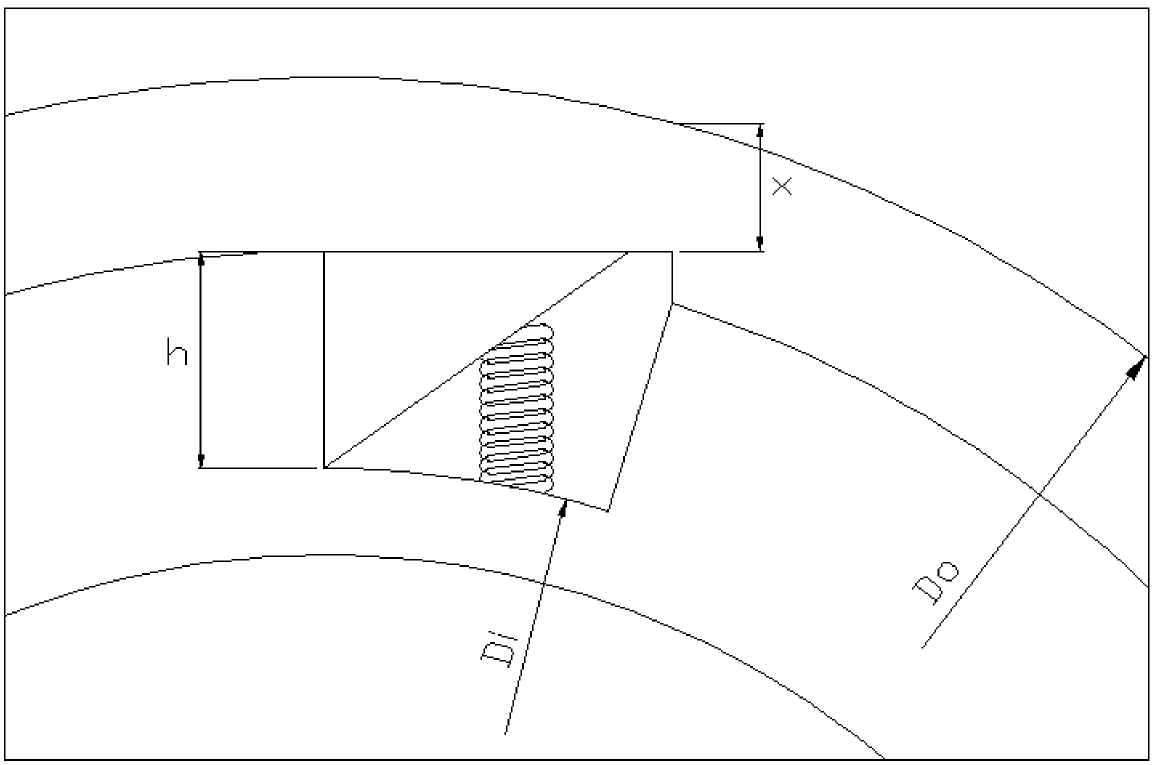

Figure 5: Dimensions for calculating hub bursting stress

Stress:

$St = T/AYn$ where T = torque

A = Area (XL)

Y = radius of applied force

n = number of locking pawls

Radius of applied force, $Y = (2D_i + h) / 4$

Note: only applicable if $X > (D_o – D_i) / 8$

$X = (D_o/2) – h - (D_i/2)$

Where, Do = outside diameter (m)

Di = inside diameter (m)

h = height of key (m)

CHAPTER 3

METHODOLOGY / PROJECT WORK

The flowchart below (Figure 6) shows the design methodology of the project:

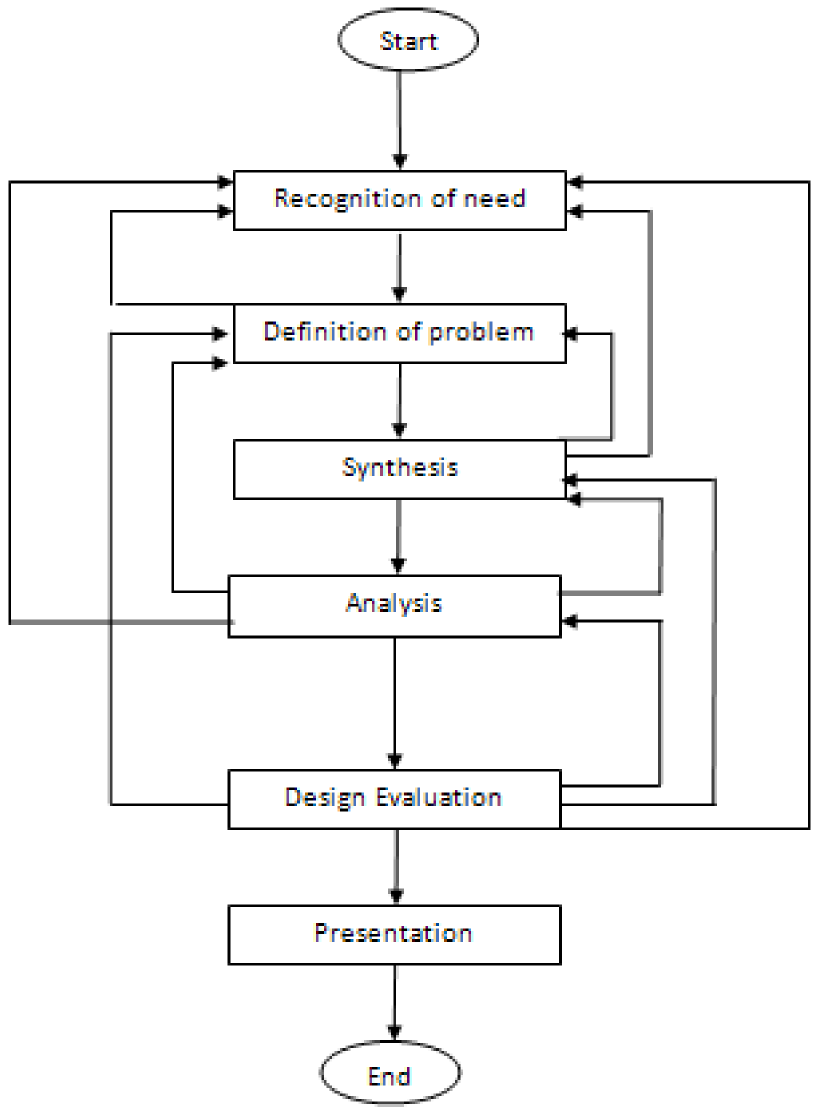

Figure 6: Design Methodology

Recognition of Need

- Brief study and explanation of generator set
- Detail study on coupling design and application
- Study on design standard for coupling.

Definition of Problem

- Definition on what is the problem with currently used coupling that will be overcome
- Justification on the specific generator set rating since there are wide ratings of generator set.
    - Engine speed
    - Torque
    - Engine power
    - Power transmission

Synthesis

- Try to invent new design based on research from the similar coupling design and application.
- Explain the new design (mechanism, mathematical, etc)
- To make sure the design can overcome the problem.

Analysis

- Provide technical drawing.
- Make the prototype to show the working mechanism of the design.
- Calculation:
    - Coupling design
    - Material selection.
    - Spring design

Evaluation

- To proof the successfulness oh the design by making the prototype.
- Testing prototype in laboratory

The flowchart below (Figure 7) shows the material selection methodology of the project:

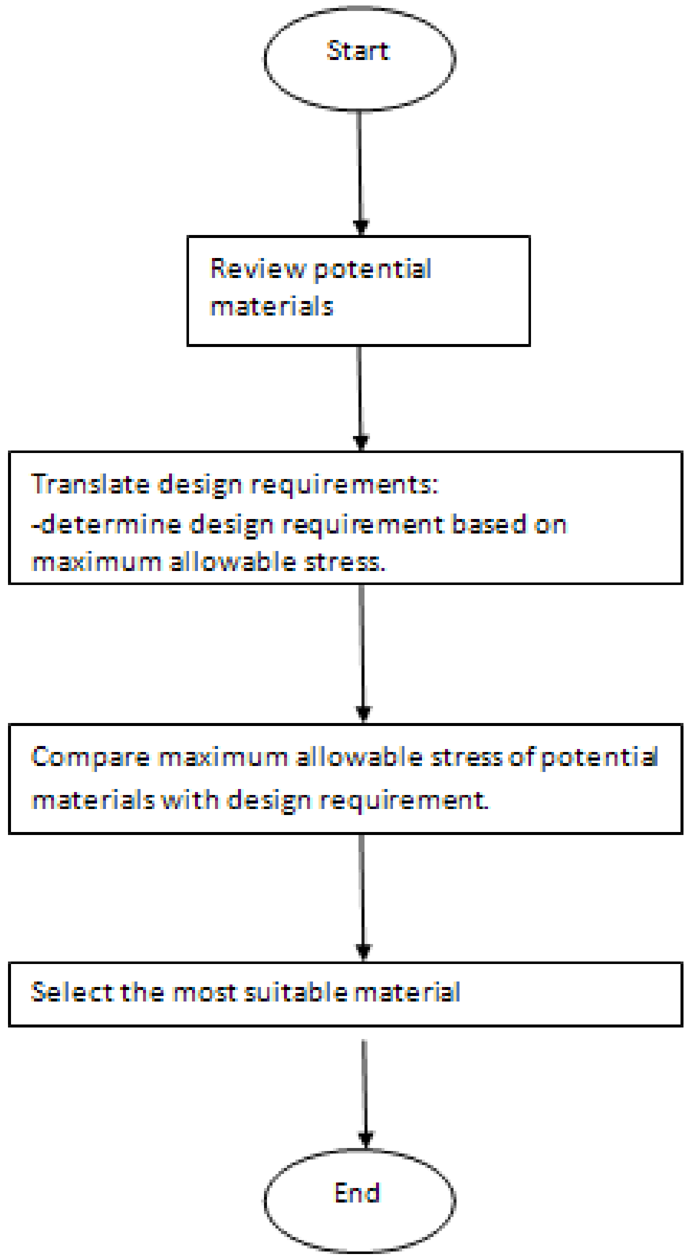

Figure 7: Material Selection Methodology

<u>Table 4: Machines use for fabrication</u>

Equipment	Image	Technical Specification	Manufacturing process
Linear Hacksaw		Model : EASTAR KP 280	To cut raw material into rough specified dimension
Heavy Duty Lathe Machine		Supply Voltage : 415 VAC Frequency : 50 Hz Control Voltage : 24 VAC Phase : 3 Power : 9 kW	To remove metal in circular shape accurately. Tolerance ± 0.1 mm
Universal Milling Machine		Supply Voltage : 415 VAC Frequency : 50 Hz Control Voltage : 24 VAC Phase : 3 Power : 8 kW	To remove material in linear direction. Tolerance ± 0.1 mm
Gas Tungsten Arc Welding (GTAW) Machine		Model NO. : Triple 35c Rated Input Voltage : 415 V Rated Load Voltage : 21 V Rated Output Current : 350 A Rated Frequency : 50~60 Hz	To joins metals by melting the workpieces and adding a filler material to form a pool of molten and let material cools to become a strong joint
Hydraulic Shearing Machine		Type : H-414 Motor : 415V / 50 Hz / 3PH Size : 52" x 14 GA , M.S. Date : June 15 2003 S.P.M : 30 No. : 920515	To cut plate metal into specified dimension by means of shearing force.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 FINDINGS

Information regarding the design specification is obtained. The design will be based on:

1) PETRONAS Technical Standard (**PTS**) [6]
2) ANSI/AGMA 9112--A04 *Bores and Keyways for Flexible Couplings (Metric Series)* [7]

PTS 31.29.80.30 (DECEMBER 2000) [6]

3.13 SHAFT COUPLINGS AND GUARDS

The packager will usually supply any shaft couplings between the engine and the driven equipment, unless otherwise stated in the requisition.

All couplings shall either be flange-bolted to shafts or be hydraulically fitted to cylindrical or
tapered shafts. Couplings requiring heating for installation or removal shall not be used.

All couplings shall be of the non-lubricated type.

All moving parts shall be protected from human contact by suitable guards of either sheet
or mesh material. All such guards shall be non-sparking. Aluminium is not regarded as a non-sparking material. Guards for belt drives (3.7.5, refer to PTS) shall be of the open mesh type.

ANSI/AGMA 9112--A04 *Bores and Keyways for Flexible Couplings (Metric Series)* [7]

This standard describes sizes and tolerances for straight and tapered bores and the associated keys and keyways, as furnished in flexible couplings. The data in the standard considers commercially standard coupling bores and keyways, not special coupling bores and keyways that may require special tolerances. Annexes provide material on inspection methods and design practices for tapered shafts.

4.2 DESIGN EXPLANATION

The new design of freewheel coupling is to provide freewheel effect by the coupling. This purpose is to allow the engine shaft and radiator shaft to rotate independently from each other so that the fan will keep on rotating although the engine stop until the fan stops by itself.

In the next part, there are explanations on the details of the new design of the free-wheel coupling.

With reference to Figure 9, the coupling sleeve **1** is connected to a shaft. The coupling sleeve **1** is rotatable around the rotational axis **3**. The coupling sleeve **1** has a support bore **4**, centered on the rotational axis **3**. Support recesses **5** are arranged around the circumference of the bore **4**. The recesses **5** have support faces which extend parallel to the rotational axis **3**. Six support recesses **5** are shown. The support recesses **5** are arranged equally distanced around the circumference of the support bore **4**.

A coupling hub **2** is arranged in the support bore **4** of the coupling sleeve **1**. The coupling hub **2** has its cylindrical outer face rotatably supported in the bore **4**. The coupling hub **2** on its circumference has six distributedly arranged recesses **6**. The recesses **6** extend parallel to the rotational axis **3**. Locking pawls **7** are pivotably supported around axes in the recesses **6**. The locking pawls extend parallel to the rotational axis **3**.

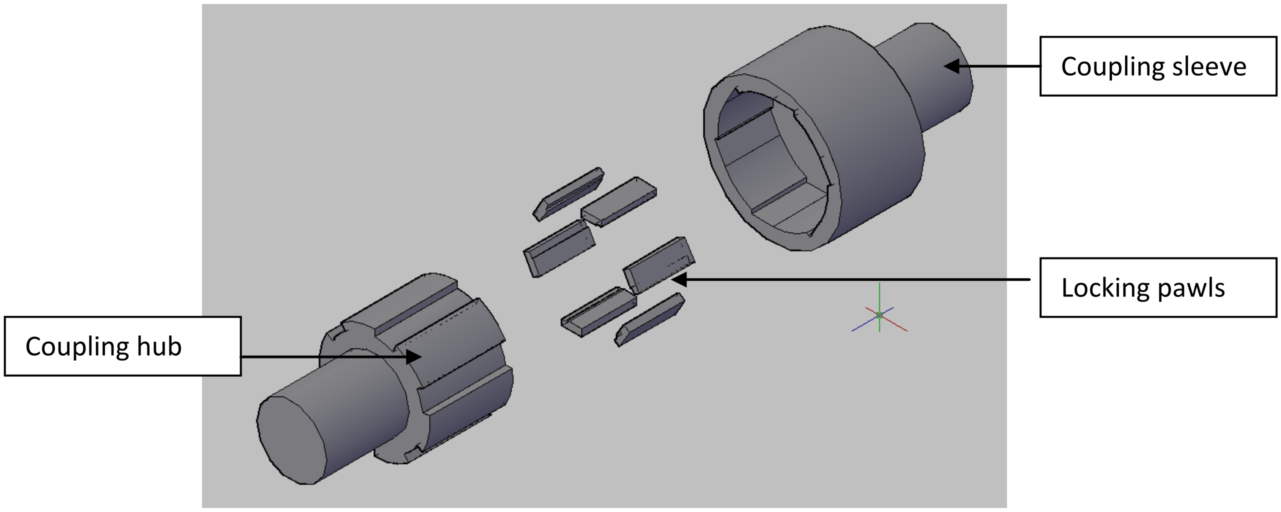

Figure 8: 3D View of Freewheel Coupling

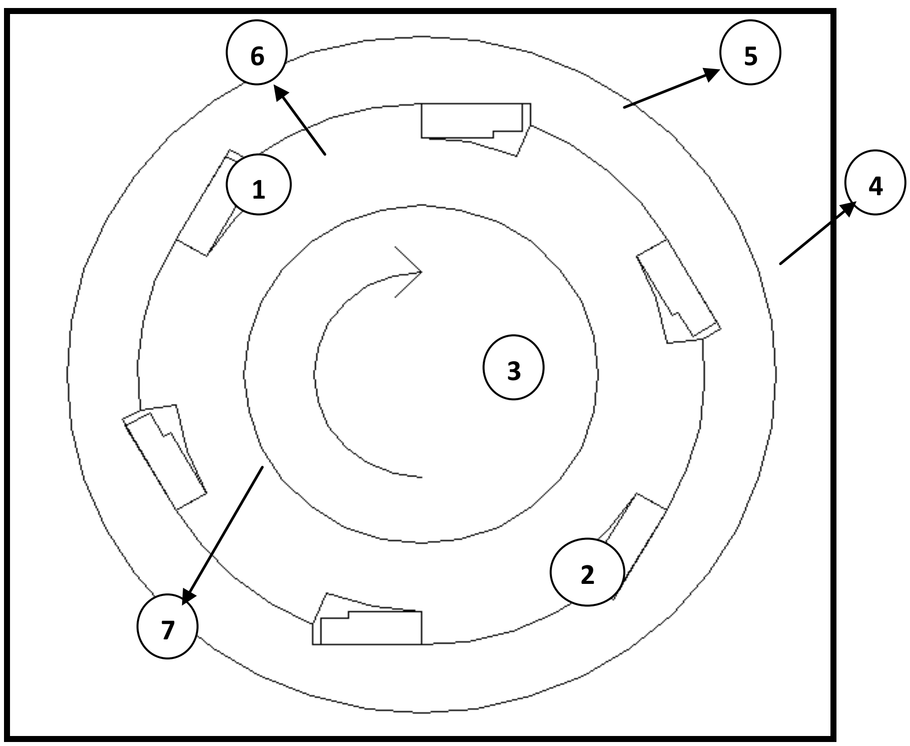

Figure 9: Design overview

The details designs are shown at Appendix 1, 2, 3 and 4.

Figure 10, 11, and 12 shows the prototype parts while Figure 13 shows the assembly of the freewheel coupling.

Figure 10: Coupling Sleeve

Figure 11: Coupling Hub

Figure 12: Locking Pawl

Figure 13: Freewheel coupling prototype assembly

4.3 Design Parameters and Calculations

Since there are wide ratings of generators that are used today, there are also many sizes of coupling that are being used. For this project, it refers to a generator set which supply 1000kW power, operating at 1800rpm. The following calculations are based on the formulas from Couplings and Joints, Design, Selection, and Application handbook [5].

4.3.1 Design Analysis

- Based on Appendix 10 [8], the best material for rotating parts like shafts and coupling design is medium carbon steels.
- Referring to Appendix 7, 8 and 9 [8], the material properties of medium carbon steel are as follows:

  - Yield strength, σ_y = 305-900 Mpa
  - Tensile strength, σ_{ts} = 410-1200 Mpa
  - Density, ρ = 7.8-7.9 Mg/m^3
  - Melting temperature, T_m and glass temperature, T_g = 1380-1514 ˚C
  - Young's modulus, E = 200-216 GPa

- Calculations performed below are based on actual dimension of the design as shown in Appendixes 1, 2, 3, 4 and Figure 14 and 15.
-

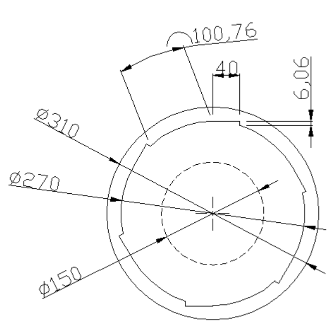

Figure 14: Coupling sleeve details

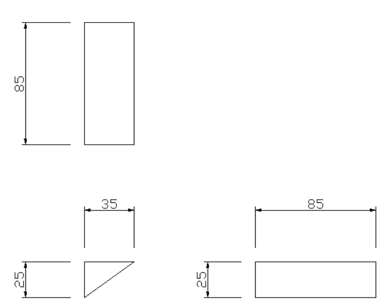

Figure 15: Locking pawls details

T = Torque (N.m)

n = number of rotation (rpm)

= 1800 rpm = ω

P = Power (kW)

= 1000 kW

D_o = outside diameter (m) = 0.31m

D_i = inner diameter (m) = 0.27m

W = width of locking pawl (m) = 0.035m

L = length of locking pawl (m) = 0.085m

Torque, T = 9550P / n

= 9550(1000)/1800

= 5305.6 N.m

4.3.1.1 Centrifugal stress

Tensile strength, $S_t = \rho V^2 / g$

Yield strength, $S_{yld} = S_t$ (F.S)

Where ρ = density of material (lb/in^3)

V = velocity (in./sec)

g = acceleration (386in./sec)

Velocity, V = (D_o x π x 1800) / 60

= (12.2947 x π x 1800) / 60

= 1150.27 in./sec

Where, Outside Diameter, D_o = 310mm = 12.2047in

Factor of safety, F.S = 1.5

Tensile strength, $S_t = \rho V^2 / g$

= $[0.283 (1150.27)^2] / 386$

= 970.06 psi ≈ 6.7 MPa

Yield strength, S_{yld} = 6.7 MPa x 1.5

= 10.05 MPa

4.3.1.2 Normal Steady-state Loads

From S_t = 6.7 MPa and S_{yld} = 10.05 MPa,

$$\text{Shear stress, } \tau = 0.577S_{yld} / F.S$$
$$= 559.725 \text{ psi}$$
$$\approx 3.86 \text{ MPa}$$

Where Factor of safety, F.S = 1.5

4.3.1.3 Cyclic or Reversing Loads

$$S_{te} = S_{end} / (F.S \times K)$$
$$\tau_e = 0.577S_{end} / (F.S \times K)$$

Where S_{te} = allowable endurance limit of tensile stress (psi)

S_{end} = tensile endurance limit (psi) = 0.5Sult

K = stress concentration factor

τ_e = allowable endurance limit for shear stress (psi)

Factor of safety are 1.25-2, usually 1.5

K usually ranges from 1.25-2

$$\text{Tensile stress, } S_{te} = S_{end} / (F.S \times K)$$
$$= 0.5(85000) / (1.5 \times 1.35)$$
$$= 20987.65 \text{ psi}$$
$$\approx 144.7 \text{ MPa}$$

Shear stress, $\tau_e = 0.577S_{end} / (F.S \times K)$

$= 0.577(0.5)(85000) / (1.3 \times 1.35)$

$= 13972.93$ psi

$= 96.3$ MPa

4.3.1.4 Infrequent Peak Loads

Tensile stress, $S_t = S_{yld} / F.S$

$= 1455.09 / 1.1$

$= 1322.81$ psi

≈ 9.1 MPa

Shear stress, $\tau = 0.577S_{yld} / F.S$

$= 0.577 (1455.09) / 1.1$

$= 763.26$ psi

≈ 5.26 MPa

4.3.1.5 Shaft stress

Engine shaft (solid);

Shear stress, $\tau_S = 16T / \pi D_o^3$

$= 16 (5305.6) / \pi (0.3^3)$

$= 1.00 \times 10^6$ N/m^2

$= 1.00$ Mpa

Connection from radiator shaft (tubular);

Shear stress, $\tau_S = 16\ TD_o / \pi (D_o^4 - Di^4)$

$= 16 (5306.5)(0.3) / \pi (0.3^4 - 0.24^4)$

$= 1.69$ Mpa

Where, Torque, T = 5305.6 N.m

Outside Diameter, Do = 0.3 m

Inner diameter, Di = 0.24 m

4.3.1.6 Key stresses

$F = 2T / D_o n$

$= 2 (5305.6) / (0.24)(6)$

$= 7369$ N

Shear stress, $S_s = F / WL$

$= 7369 / (0.042)(0.15)$

$= 1.17$Mpa

Compressive stress, $S_c = 2F / hL$

$= 2(7369) / (0.015)(0.15)$

$= 6.56$ Mpa

4.3.1.7 Hub stresses and capacities

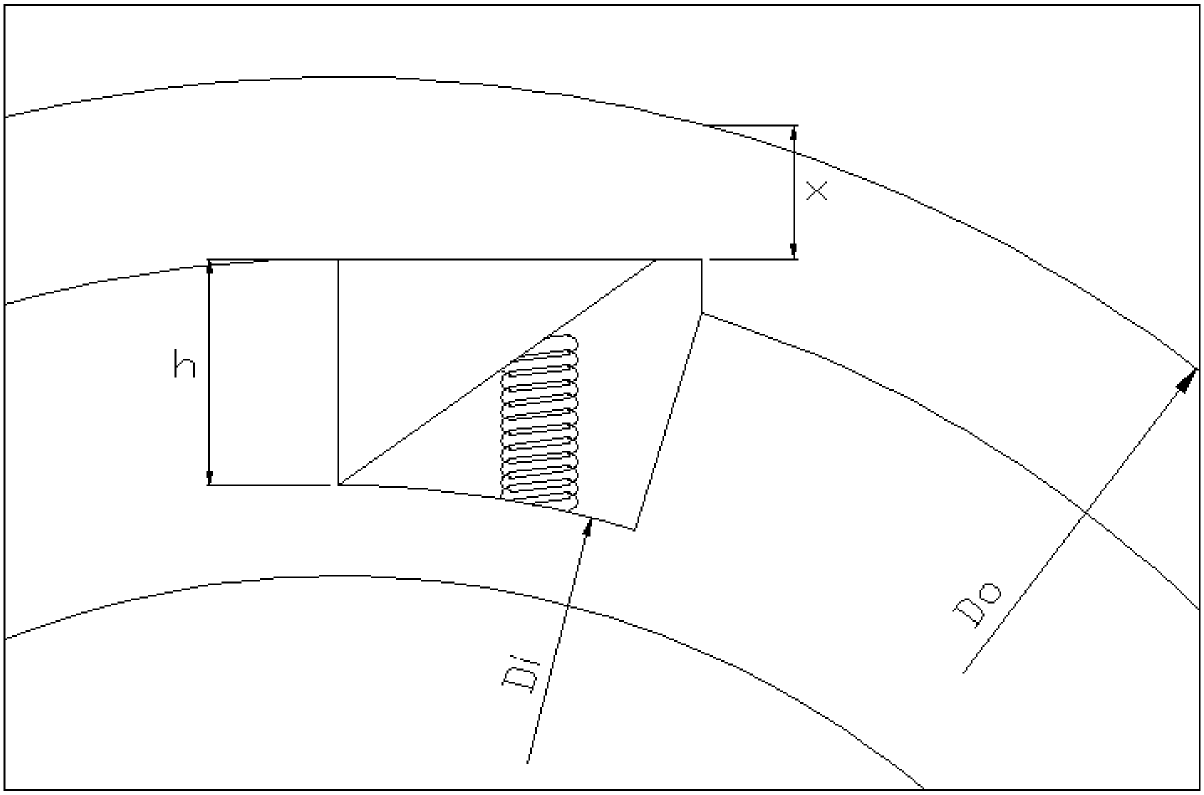

Figure 16: Dimensions for calculating hub bursting stress

Stress:

Tensile stress, St = T/AYn

Where,

T = torque = 5305.6 N.m

A = Area (XL)

Y = radius of applied force

Number of locking pawls, n = 6

Outside Diameter, Do = 0.31 m

Inner diameter, Di = 0.22 m

Height of key, h = 0.025 m

Radius of applied force, $Y = (2D_i + h) / 4$

Note: only applicable if $X > (D_o – D_i) / 8$

$X = (D_o/2) – h – (D_i/2)$

$= (0.31/2) – 0.025 – (0.22/2)$

$= 0.155 – 0.025 – 0.11$

$= 0.02$ m

$(D_o – D_i) / 8 = (0.31 – 0.22) / 8$

$= 0.01125$ m

From the calculations, it shows that $X > (D_o – D_i) / 8$ so the formula to calculate Radius of applied force, Y is applicable.

Radius of applied force, Y

$Y = (2Di + h) / 4$

$= [(2 \times 0.22) + 0.025] / 4$

$= 0.11625$

Tensile stress, St

$St = T / AYn$

$= 5305.6 / (0.02)(0.085)(0.11625)(6)$

$= 4.47$ Mpa

	Tensile Strength, S_t (MPa)	Yield Strength, S_{yld} (MPa)	Shear Stress, τ (MPa)	Compressive Stress, S_c (MPa)
Centrifugal stress	6.7	10.05	-	-
Normal Steady-State Loads	6.7	-	3.86	-
Cyclic Loads	144.7	-	96.3	-
Infrequent Peak Loads	9.1	-	5.26	-
Shaft Stress (Engine Shaft)	-	-	1.95	-
Shaft Stress (Radiator Shaft)	-	-	1.69	-
Key Stress	-	-	1.17	6.56
Hub Stress	9.69	-	-	-

Table 5: Summary of strength calculated in the design

- From the analysis, it shows that the maximum required strength is **144.7 MPa**.
- Selected material must be:
  - Greater allowable strength compared to design strength requirement.
  - Corrosion resistance.
- Thus, the best material for the design is **Stainless Steel 316L**:
  - Density, $\rho = 7.8 \text{ Mg/m}^3$
  - Young's Modulus, E = 210 GPa
  - Yield strength, σ_y = 1000 MPa
  - Tensile strength, σ_{ts} = 2240 MPa
  - Corrosion resistances

CHAPTER 5

CONCLUSION AND RECOMMENDATION

CONCLUSION

As a conclusion, the project has achieved its objective to design a freewheel coupling that allows the radiator fan to stop by itself after the engine stop, instead of stopping suddenly right after the engine shut down. The design can overcome the problems which, the sudden stop will create a high torsional effect onto the bolting and the crank shaft Power Transmitted Output (PTO) end, where it will cause the bolting to fail, twisting effect on the PTO end, and it will also create impact to the blade which it will cause the blade to snap. This project has gone through various process such as designing, cost analysis, fabrication, and the project evaluation to make sure the end product will reach all the specification and requirement. Besides the prototype, a final report, which explains all the information that was used in the process of completing the project, compiled as a reference so that further research can be made. This project will benefit both the packager of the generator set, and also the end user, to the issues in cost and design that overcome the problem stated above.

RECOMMENDATION

1) Since this project uses steel, so there will be noise emitted during operation because the locking pawl will keep on slamming the coupling sleeve’s surface area every time it reaches each the support recesses. In order to overcome this noise problem, coating or using another material for the locking pawl, can be considered. A proper planning would ensure this project to stay on track to produce the outcome of this project.
2) The spring design and analysis are not completed in this project. So there are still further studies that have to be done in order to complete the design requirement.

REFERENCES

1. Website : ***http://en.wikipedia.org/wiki/Diesel_generator***
2. Website : ***http://www.answers.com/topic/diesel-engine?cat=technology***
3. Hindhede / Zimmerman / Hopkins / Erisman / Hull / Lang , ***"Machine Design Fundamentals, A Practical Approach"*** , 1983, pp. 236.
4. Website : ***http://www.mitcalc.com/doc/help/en/c_shaftcon_choice.htm***
5. Jon R. Mancuso, ***"Couplings and Joints Design, Selection, And Application"***, 1999, pg. 80-113.
6. ***PETRONAS Technical Standard*** (PTS 31.29.80.30), DECEMBER 2000
7. ***American Gear Manufacturers Association. Bore and keyways for flexible couplings. AGMA*** 9002-A86, 1986
8. Michael F. Ashby ***"Materials Selection in Mechanical Design"***, Third Edition, Butterworth-Heinemann, 2005.
9. Calistrat, M. ***"Flexible Couplings: Their Design, Selection, and Use"***, Caroline Publishing, 1994.
10. Roots, ***"Flexible Shaft Coupling"***, U.S Patent 349, 365, 1886.
11. South, D., and J. Mancuso. ***"Mechanical Power Transmission Components"***, Marcel Dekker, New York, 1994.
12. Wright, J. ***"Tracking down the cause of coupling failure. Machine Design"***, 1977.
13. Hagler, P., H. Schwerdin, and R. Esleman, ***"Effect of Shaft Misalignment,"*** Design News, January 22, 1979.
14. Farmingdale, ***"Shaft Coupling"***, N.Y.: Renold Crofts, Inc., 1972.
15. Carson, R. W. ***"New and Better Traction Drives are here," Machine Design"*** , April 18, 1974.
16. Jaeschke, R. L. ***"Controlling Power Transmission Systems"*** , Cleveland, Ohio: Penton, 1978.

APPENDICES

Appendix 1: Technical Drawing of

“General Arrangement of Freewheel Coupling Design”

Appendix 2: Technical Drawing of

“Coupling Sleeve of Freewheel Coupling Design”

Appendix 3: Technical Drawing of

"Coupling Hub of Freewheel Coupling Design"

Appendix 4: Technical Drawing of
"Locking Pawl of Freewheel Coupling Design"

Appendix 5: Names and application of metal and alloy

Names and applications: metals and alloys

Metals	Applications
Ferrous	
Cast irons	Automotive parts, engine blocks, machine tool structural parts, lathe beds
High carbon steels	Cutting tools, springs, bearings, cranks, shafts, railway track
Medium carbon steels	General mechanical engineering (tools, bearings, gears, shafts, bearings)
Low carbon steels	Steel structures ("mild steel")—bridges, oil rigs, ships; reinforcement for concrete; automotive parts, car body panels; galvanized sheet; packaging (cans, drums)
Low alloy steels	Springs, tools, ball bearings, automotive parts (gears connecting rods, etc.)
Stainless steels	Transport, chemical and food processing plant, nuclear plant, domestic ware (cutlery, washing machines, stovès), surgical implements, pipes, pressure vessels, liquid gas containers
Non-ferrous	
Aluminum alloys	
Casting alloys	Automotive parts (cylinder blocks), domestic appliances (irons)
Non-heat-treatable alloys	Electrical conductors, heat exchangers, foil, tubes, saucepans, beverage cans, lightweight ships, architectural panels
Heat-treatable alloys	Aerospace engineering, automotive bodies and panels, lightweight structures and ships
Copper alloys	Electrical conductors and wire, electronic circuit boards, heat exchangers, boilers, cookware, coinage, sculptures
Lead alloys	Roof and wall cladding, solder, X-ray shielding, battery electrodes
Magnesium alloys	Automotive castings, wheels, general lightweight castings for transport, nuclear fuel containers; principal alloying addition to aluminum alloys
Nickel alloys	Gas turbines and jet engines, thermocouples, coinage; alloying addition to austenitic stainless steels
Titanium alloys	Aircraft turbine blades; general structural aerospace applications; biomedical implants.
Zinc alloys	Die castings (automotive, domestic appliances, toys, handles); coating on galvanized steel

Appendix 6: Yield Strength and Tensile Strength of materials

	σ_y (MPa)	σ_{ts} (MPa)
Metals		
Ferrous		
Cast irons	215–790	350–1000
High carbon steels	400–1155	550–1640
Medium carbon steels	305–900	410–1200
Low carbon steels	250–395	345–580
Low alloy steels	400–1100	460–1200
Stainless steels	170–1000	480–2240
Non-ferrous		
Aluminum alloys	30–500	58–550
Copper alloys	30–500	100–550
Lead alloys	8–14	12–20
Magnesium alloys	70–400	185–475
Nickel alloys	70–1100	345–1200
Titanium alloys	250–1245	300–1625
Zinc alloys	80–450	135–520
Ceramics		
Glasses		
Borosilicate glass (*)	264–384	22–32
Glass ceramic (*)	750–2129	62–177
Silica glass (*)	1100–1600	45–155
Soda-lime glass (*)	360–420	31–35
Porous		
Brick (*)	50–140	7–14
Concrete, typical (*)	32–60	2–6
Stone (*)	34–248	5–17
Technical		
Alumina (*)	690–5500	350–665
Aluminum nitride (*)	1970–2700	197–270
Boron carbide (*)	2583–5687	350–560
Silicon (*)	3200–3460	160–180
Silicon carbide (*)	1000–5250	370–680
Silicon nitride (*)	524–5500	690–800
Tungsten carbide (*)	3347–6833	370–550
Composites		
Metal		
Aluminum/silicon carbide	280–324	290–365
Polymer		
CFRP	550–1050	550–1050
GFRP	110–192	138–241

Appendix 7: Young Modulus of Materials

Young's modulus, E

	E (GPa)
Metals	
Ferrous	
Cast irons	165–180
High carbon steels	200–215
Medium carbon steels	200–216
Low carbon steels	200–215
Low alloy steels	201–217
Stainless steels	189–210
Non-ferrous	
Aluminum alloys	68–82
Copper alloys	112–148
Lead alloys	12.5–15
Magnesium alloys	42–47
Nickel alloys	190–220
Titanium alloys	90–120
Zinc alloys	68–95
Ceramics	
Glasses	
Borosilicate glass	61–64
Glass ceramic	64–110
Silica glass	68–74
Soda-lime glass	68–72
Porous	
Brick	10–50
Concrete, typical	25–38
Stone	120–133
Technical	
Alumina	215–413
Aluminum nitride	302–348
Boron carbide	400–472
Silicon	140–155
Silicon carbide	300–460
Silicon nitride	280–310
Tungsten carbide	600–720
Composites	
Metal	
Aluminum/silicon carbide	81–100
Polymer	
CFRP	69–150
GFRP	15–28

Appendix 8: Density of Materials

Density, ρ

	ρ (Mg/m^3)
Metals	
Ferrous	
Cast irons	7.05–7.25
High carbon steels	7.8–7.9
Medium carbon steels	7.8–7.9
Low carbon steels	7.8–7.9
Low alloy steels	7.8–7.9
Stainless steels	7.6–8.1
Non-ferrous	
Aluminum alloys	2.5–2.9
Copper alloys	8.93–8.94
Lead alloys	10–11.4
Magnesium alloys	1.74–1.95
Nickel alloys	8.83–8.95
Titanium alloys	4.4–4.8
Zinc alloys	4.95–7
Ceramics	
Glasses	
Borosilicate glass	2.2–2.3
Glass ceramic	2.2–2.8
Silica glass	2.17–2.22
Soda-lime glass	2.44–2.49
Porous	
Brick	1.9–2.1
Concrete, typical	2.2–2.6
Stone	2.5–3
Technical	
Alumina	3.5–3.98
Aluminum nitride	3.26–3.33
Boron carbide	2.35–2.55
Silicon	2.3–2.35
Silicon carbide	3–3.21
Silicon nitride	3–3.29
Tungsten carbide	15.3–15.9
Composites	
Metal	
Aluminum/silicon carbide	2.66–2.9
Polymer	
CFRP	1.5–1.6
GFRP	1.75