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Design of a protected type flange coupling using Python

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ABSTRACT

Couplings are elements used to connect two shafts during power transmission. Design of couplings plays a vital role in determining the power transmission capacity of the shaft at the rated rpm, which is very crucial. The design specification of coupling varies differently based on the requirements and involves a sequential design procedure which is tedious and time-consuming. This paper deals with developing 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 optimised way of designing machine elements and aims to give better clarity to shop floor workers.

Keywords— Couplings, Python programming, Design analysis

1. INTRODUCTION

With the advent of technology and the focus of industries shifting towards optimising time and cost, usage of manual methods for designing machine elements prove tedious. Moreover, the use of standard bulky equations for design of machine elements (like couplings) is a monotonous job to do and time consuming, which also includes a fair chance of human errors resulting in comparatively faulty design which might lead to a defective product. To overcome these difficulties, the design equations can be fed in a system and with the help of programming languages, machine elements can be designed with great ease with greater accuracy, less time, less efforts and fairly less cost. This paper shows using PYTHON as a programming language to ease the design procedure. Moreover, the python code used is parametric, i.e., it need not be written every time but once a programmer has coded a set of instructions using logic statements in a OOP language, it can be used for any parameter, resulting in saving time and avoiding hectic hours of calculating the specifications each time for a same machine element of a different material. A coupling is a machine element used to connect two shafts together at their ends for transmitting power. The primary purpose of couplings is to join two shafts while permitting some degree of misalignment or end movement or both. Generally, couplings are used to connect one shaft to another or to couple a drive shaft to a driven shaft. They are used to provide a connection for the shafts of units that are manufactured separately such as a motor and a pump, turbine & generator etc... Couplings are provided so that if any faults are there on any of the shaft then they can be easily disconnected and repair or alternation can be done. Couplings offer mechanical flexibility, avoid buckling of shafts due to self-weight, reduce transmission of shock loads from one shaft to other and also alter the vibration characteristics of rotating units produced during transmission.

Based on the industrial requirement, couplings can be majorly divided into two types: Rigid couplings and Flexible couplings. Examples of Rigid couplings include Muff or sleeve couplings, Marine type flange coupling and Protected or Unprotected type flange coupling. Examples of Flexible couplings include Oldham coupling, Universal coupling or Bush pin type flexible coupling. This paper deals with the design of protected type flange coupling which will be discussed in the further sections.

The research work [1] carried out by the author is based on the approach of a CADD (Computer Aided Design and Drafting) and Concurrent engineering. The work reviews the procedural steps involved in the design of couplings and the development of the software package using visual basic as a tool for the design. This system is carried out on the case study of flange coupling and standard design equation being carried out together with the use of programming software and use CREO as modelling software after getting output from the designing software.

[2]This paper deals with design of transmission shafts using C programming code. It aims towards easing the process of determining suitable diameter of shaft by traditional methods which are tedious and time consuming. A program code is written which determines diameter by considering length of shaft, power transmitted, rpm of shaft, diameter of pulleys and gears, tension ratios of pulleys, pressure angles of gear and position of gears and pulleys on shaft. The main objective of the paper is to write a generalised program using C programming language applicable for design of all transmission shafts with mountings.

2. PROTECTED TYPE FLANGE COUPLING

There are two separate cast iron flanges, one keyed to the driven shaft, another to the driving shaft by means of nuts and bolts arranged on an imaginary circle concentric with the axes of the shafts. Protected type flange couplings have projecting circumferential rims that cover the head of the bolts and nuts, as a consequence of which, during bolt failure while the machine is running, the broken pieces will hit the rim and eventually fall down, protecting the operator.

3. METHODOLOGY

The methodology followed is as follows. There are certain assumptions that are considered in the design of this protected type flange coupling which are mentioned below.

Assumptions:

- The material of the shaft, key and bolt is considered to be same so as to maintain the same young's modulus and ensure that failure occurs at the same time.
- The values entered by the user for power input, rpm input, FOS input are all non- negative, non-zero numbers.

The design equations used for the design of protected type flange coupling has been provided in steps below:

- Power : The user enters the desired power in kw
- Rpm: The user enters the number of rotations of shaft in rpm
- FOS: The user enters the factor of safety for shaft, key and bolt
- FOS2: The user enters the factor of safety for flange
- A list appears on the console that shows the available set of materials for the shaft and key and bolt.
- The user chooses one material from the list and the yield stress of that particular material is imported from the excel sheet that contains the stress values of different materials.
- The allowable stress of the material, the crushing stress of bolt and the torque are calculated by the following formulas:

$$\text{Allowable stress} = \frac{\text{Yield stress}}{\text{FOS}}$$

$$\text{Crushing stress} = 2 \times \text{Allowable stress}$$

$$\text{Torque} = 9.55 \times 10^6 \times \frac{\text{Power}}{\text{rpm}}$$

- The diameter of the shaft is calculated,

$$d = \sqrt[3]{\frac{16 \times \text{Torque}}{\pi \times (\text{Allowable stress})}}$$

- The standard values of diameter of shaft are imported from excel sheet.
- The number of bolts is calculated = $(\frac{1}{40} \times \text{Standard diameter}) + 2$
- The standard number of bolt is calculated by using appropriate formula which should be an even number.
- The bolt diameter is calculated by: $\frac{0.423 \times \text{Standard diameter}}{\sqrt[3]{\text{bolts} + 7.5}}$
- The standard bolt diameter value is imported from the excel sheet.
- The diameter of hub and the bolt circle diameter along with the hub length is calculated by appropriate formulas:
 Diameter of hub = $(1.5 \times \text{Standard diameter}) + 25$
 Bolt circle diameter = Diameter of hub + $(3.2 \times \text{Standard bolt})$
 Hub length = $(1.2 \times \text{Standard diameter}) + 20$
- The shear stress in bolt is calculated and the value is compared to the data of allowable stress of the corresponding material from the database as in the flow chart.
- If design is safe, the width and height of the key are calculated based on the shaft size and is imported from the database.
- For calculating the length of the key, the shearing and the crushing stresses are considered (acting on the key). The length of the key obtained from the two cases is observed and the higher value of those two is taken as the length of the key.
- The outside diameter and the thickness of the flange are determined by using suitable formulas:
 Outside diameter = Hub diameter + $(6 \times \text{Standard bolt size})$
 Thickness = $(0.35 \times \text{Standard diameter of shaft}) + 9$
- The induced shear stress in flange is calculated and this stress is compared to the allowable stresses of the list of materials available for designing the flange, mentioned in the database.

$$\text{Induced_shear_in_flange} = \frac{2 \times \text{Torque}}{\pi \times \text{Hub diameter} \times \text{Hub diameter} \times \text{Flange thickness}}$$

- Since this is a protected type flange coupling, so the protected parameters like a, b, c, f, t₁, t₂, t₃ are also determined using the relation

$$a = (0.2 \times \text{Standard diameter of shaft}) + 5$$

$$b = (0.5 \times \text{Standard diameter of shaft}) + 25$$

$$(0.3 \times \text{Standard diameter of shaft}) + (1.3 \times \text{Standard diameter of bolt}) + 7.55$$

$$c = (0.1 \times \text{Standard diameter of shaft}) + 2.5$$

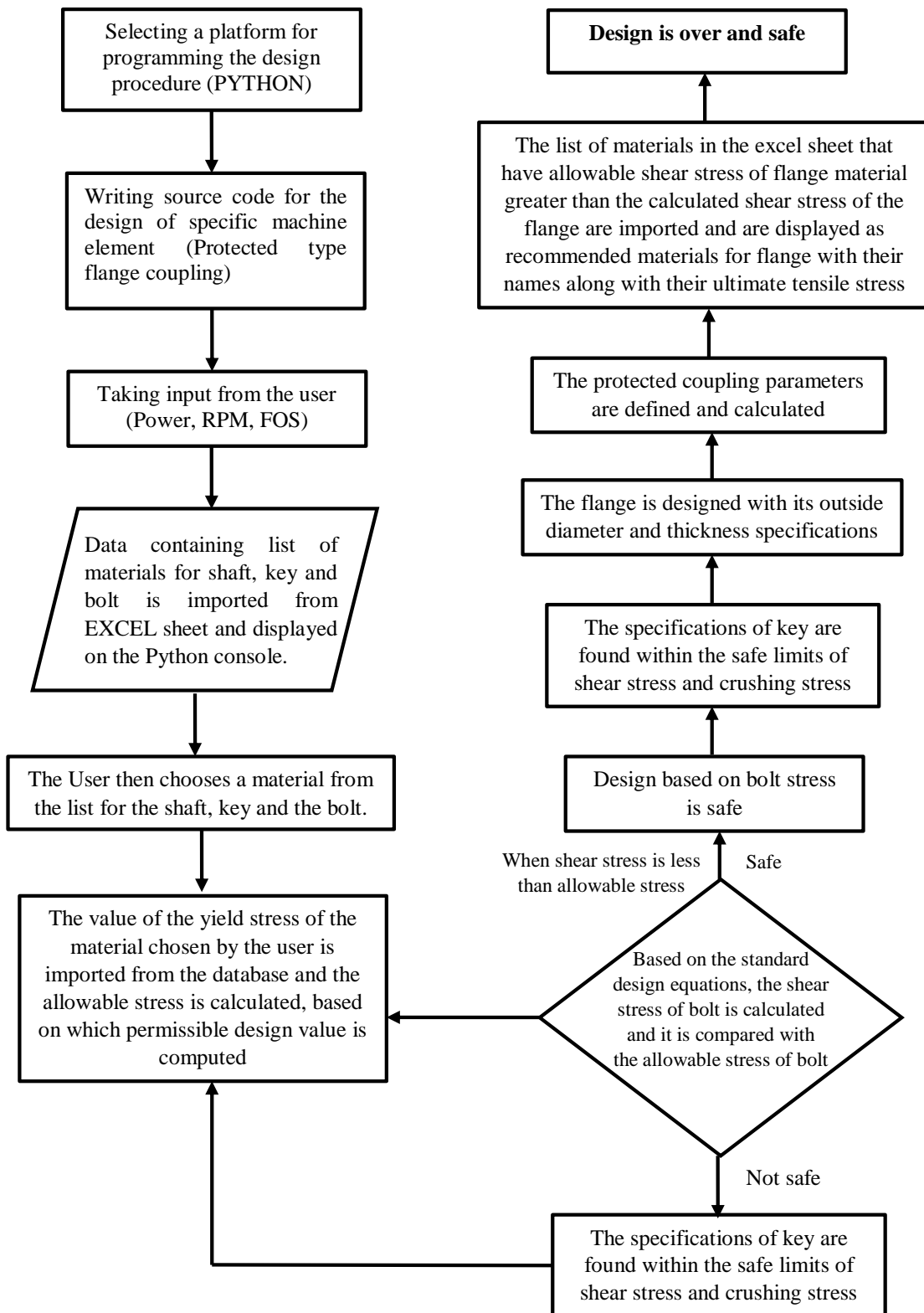
$$f = 1.5 \times \text{Standard diameter of shaft}$$

} whichever is greater

$$t_1 = (0.25 \times \text{Standard diameter of shaft}) + 6.35$$

$$t_2 = (0.3 \times \text{Standard diameter of shaft}) + 7$$

$$t_3 = (0.1 \times \text{Standard diameter of shaft}) + 5$$



4. PROGRAM SOURCE CODE (PYTHON)

```

import math
power=input('enter the desired power in kw: ')
rpm=input('enter the number of rotations of shaft in rpm: ')
FOS=input('enter the factor of safety for shaft , key and bolt: ')
FOS2=input('enter the factor of safety for flange: ')
print('The list given below shows the available set of materials for the shaft and key: ')
import xlrd
ExcelFileName= 'C:\\Users\\HP\\Desktop\\DME_assignment.xlsx'
    
```

```
workbook = xlrd.open_workbook(ExcelFileName)
worksheet = workbook.sheet_by_name("Sheet1")
worksheet2 = workbook.sheet_by_name("Sheet2")
worksheet3 = workbook.sheet_by_name("Sheet3")
num_rows = worksheet.nrows
num_cols = worksheet.ncols
sheet2_rows = worksheet2.nrows
sheet2_cols = worksheet2.ncols
sheet3_rows = worksheet3.nrows

materials=[]
for curr_row in range(0, num_rows):
    data = worksheet.cell_value(curr_row,0)
    materials.append(data)
for each in materials:
    print(each)
print('Assuming that the shaft and key material is same as that of the bolt material!!!')
materialData = input('Enter the material of the shaft, key and bolt:\n')
row_value = -1
for curr_row in range(2, num_rows):
    data = worksheet.cell_value(curr_row, 0)
    if (data == materialData):
        row_value = curr_row
        print('The YIELD stress OF the shaft, key and bolt is : ',worksheet.cell_value(curr_row,1))

properties = []
if row_value != -1:
    for cols in range(1, num_cols):
        properties.append(worksheet.cell_value(row_value, cols))

data_value = properties[0]
allow= (data_value/float(FOS))
print('The allowable shear stress of the shaft, key and bolt is : ',allow)
crushstress=(2*allow)
print('The crushing stress of key is : ')
print(crushstress)
torque= (9.55e6 * (float(power))/float(rpm))
print('The torque transmitted by the shaft in N-mm is : ')
print(torque)
diam=((16*torque)/(3.14*float(allow)))*(1/3)
print('The diameter of the shaft is (in mm): ',diam)

size = []
i=1
sizerow = 1
while sizerow < sheet3_rows:
    if float(worksheet3.cell_value(sizerow,0)) >= diam:
        std_diam=float(worksheet3.cell_value(sizerow,0))
        size.append(std_diam)
        print('The standard shaft size in mm is : ',std_diam)
        no_of_bolts = float(((1/40)*std_diam) + 2)
        print(' The number of bolts is : ')
        print(no_of_bolts)
        print('The standard number of bolts are : ')
        bolts=float((math.ceil(no_of_bolts)))
        if bolts %2==0:
            print(bolts)

        else:
            bolts = bolts + 1
            print(bolts)

        bolt_diam = float(((0.423*std_diam)/math.sqrt(bolts)) +7.5)
        print('The diameter of the bolt is : ',bolt_diam)
        bolt=[]
        for boltrow in range(1,sheet3_rows):
```

```
if float(worksheet3.cell_value(boltrow,1))>=bolt_diam:
    print("The standard diameter of the bolt is : ")
    std_bolt=float((worksheet3.cell_value(boltrow,1)))
    bolt.append(std_bolt)
    print(std_bolt)
    break
else:
    continue

diam_hub = float((1.5*std_diam)+25)
print("The diameter of the hub is: ")
print(diam_hub)
bolt_circle_diam = float(diam_hub + (3.2*std_bolt))
print("The bolt circle diameter is : ")
print(bolt_circle_diam)
hub_length= float((1.2*std_diam) + 20)
print("The hub length is : ")
print(hub_length)

shear_in_bolt = float((8*torque)/(3.14*bolts*bolt_circle_diam*std_bolt))
print("The shear stress in bolt is calculated to be : ',shear_in_bolt)

if (float(shear_in_bolt)>float(allow)):
    print("\nYour design is unsafe as the shear stress of bolt exceeds the allowable stress of bolt\n\n\n')
    sizerow +=1
    i+=1
    print('ITERATION NO: ',i)
    continue

else:
    print("\n\nDesign based on shear stress of bolt is safe\n\n\n')
    break

else:
    sizerow+=1
    continue

shaft_upper_width=[]
shaft_upper_height=[]
for shaft_upper_row in range(1,27):
    if float((worksheet3.cell_value(shaft_upper_row,3))>std_diam):
        width_key=float((worksheet3.cell_value(shaft_upper_row,4)))
        height_key=float((worksheet3.cell_value(shaft_upper_row,5)))
        shaft_upper_width.append(width_key)
        shaft_upper_height.append(height_key)
        print("The width of key is : ',width_key)
        print("The height of key is : ',height_key)
        break

else:
    continue

shear_length_key =float((2*torque)/(0.5*crushstress*std_diam*width_key))
crush_length_key = float((4*torque)/(crushstress*height_key*std_diam))

if(shear_length_key > crush_length_key):
    length_key = shear_length_key
else:
    length_key=crush_length_key

print("The length of the key is : ',length_key)

flange_out_diam= float(diam_hub + (6*std_bolt))
flange_thickness = float((0.35*std_diam)+ 9)
print("The outside diam and thickness of flange are : ',flange_out_diam,' ',flange_thickness)
print("\n\nThe additional parameters of this protected flange coupling are shown below: ')
```

```

a=float((0.2*std_diam)+5)
max1=float((0.5*std_diam)+25)
max2=float((0.3*std_diam)+(1.3*std_bolt)+7.55)
if max1>max2 :
    b=max1

else:
    b=max2

c=float((0.1*std_diam)+2.5)
f=float(1.5*std_diam)
t1=float((0.25*std_diam)+6.35)
t2=float((0.3*std_diam)+7)
t3=float((0.1*std_diam)+5)

shear_in_flange = float((2*torque)/(3.14*diam_hub*diam_hub*flange_thickness))
print("The induced shear stress in flange is :",shear_in_flange)
print("\n\n\n -----DESIGN SPECIFICATIONS-----")
print("\n Material Name,(' ')*(19-12),':',materialData)
print("\n Factor of safety,(' ')*(19-15),':',FOS)
print("\n Allowable stress,(' ')*(19-15),':',allow)
print("\n\n\n Power,(' ')*(19-4),':',power)
print("\n no of rotations,(' ')*(19-14),':',rpm)
print("\n Torque produced,(' ')*(19-14),':',torque)
print("\n\n\n Specifications of shaft and bolt")
print("\n\n\n Diam of shaft,(' ')*(19-12),':',std_diam)
print("\n Number of bolts,(' ')*(19-14),':',bolts)
print("\n Diameter of bolt,(' ')*(19-15),':',std_bolt)
print("\n Hub diameter,(' ')*(19-11),':',diam_hub)
print("\n Bolt circle diameter,(' ')*(0),':',bolt_circle_diam)
print("\n Hub length,(' ')*(19-9),':',hub_length)
print("\n\n\n Key specifications")
print("\n\n length,(' ')*(19-5),':',length_key)
print("\n width,(' ')*(19-4),':',width_key)
print("\n height,(' ')*(19-5),':',height_key)
print("\n\n\n Specifications of flange")
print("\n Outside diameter,(' ')*(19-15),':',flange_out_diam)
print("\n Thickness,(' ')*(19-8),':',flange_thickness)
print("\n\n\n Protected flange coupling parameters\n")
print('a : ',a,',\nb : ',b,',\nc : ',c,',\nf : ',f,',\nt1 : ',t1,',\nt2 : ',t2,',\nt3 : ',t3)
print("\n\n\n Based on calculated shear stress of flange , \nRecommended materials for the flange are :\n\n")

flange_value=[]
for row in range(1, sheet2_rows):
    value=float(0.5*worksheet2.cell_value(row,1))/float(FOS2)
    if (float(value)>= float(shear_in_flange)):
        vlues=(worksheet2.cell_value(row,1))
        names=(worksheet2.cell_value(row,0))
        flange_value.append(worksheet2.cell_value(row,0))

    else:
        continue;

for each in flange_value:
    print(each)
    print('\n')

else:
    continue

if(row_value!=-1):
    print("\n\n-----Design is over-----")

else:
    print("The material which you entered is not available in the list ")

```

-----END---OF---CODE-----

5. TEST CASE

The code can be run for any parameter from the user. Here, certain parameters are entered to show the output of the code.

USER INPUT PARAMETERS:

enter the desired power in kw: 50

enter the number of rotations of shaft in rpm: 2500

enter the factor of safety for shaft , key and bolt: 2.6

enter the factor of safety for flange: 1.8

EXCEL SHEET:

The list given below shows the available set of materials for the shaft and key:

STEEL TYPES

C40

C45

C50

C10

C65

ASSUMPTION: Assuming that the shaft and key material is same as that of the bolt material!!

USER INPUT:

Enter the material of the shaft, key and bolt:

C10

DESIGN PROCEDURE STARTS:

Using formulas mentioned above,

The yield stress of the shaft, key and bolt is : 103.0

The allowable shear stress of the shaft, key and bolt is : 39.61538461538461

The crushing stress of key is :

79.23076923076923

The torque transmitted by the shaft in N-mm is:

191000.0

The diameter of the shaft is (in mm): 29.070551777420413

The standard shaft size in mm is : 32.0

The number of bolts is :

2.8

The standard number of bolts are :

4.0

The diameter of the bolt is : 14.268

The standard diameter of the bolt is :

16.0

The diameter of the hub is:

73.0

The bolt circle diameter is :

124.2

The hub length is :

58.4

The shear stress in bolt is calculated to be : 61.219832405099645

Your design is unsafe as the shear stress of bolt exceeds the allowable stress of bolt

ITERATION NO: 2

The standard shaft size in mm is : 36.0

The number of bolts is :

2.9

The standard number of bolts are :

4.0

The diameter of the bolt is : 15.114

The standard diameter of the bolt is :

16.0

The diameter of the hub is:

79.0

The bolt circle diameter is :

130.2

The hub length is :

63.199999999999996

The shear stress in bolt is calculated to be : 58.39864197168492

Your design is unsafe as the shear stress of bolt exceeds the allowable stress of bolt

ITERATION NO: 3

The standard shaft size in mm is : 40.0

The number of bolts is :

3.0

The standard number of bolts are :

4.0

The diameter of the bolt is : 15.959999999999999

The standard diameter of the bolt is :

16.0

The diameter of the hub is:

85.0

The bolt circle diameter is :

136.2

The hub length is :

68.0

The shear stress in bolt is calculated to be : 55.826014572051214

Your design is unsafe as the shear stress of bolt exceeds the allowable stress of bolt

ITERATION NO: 4

The standard shaft size in mm is : 45.0

The number of bolts is :

3.125

The standard number of bolts are :

4.0

The diameter of the bolt is : 17.0175

The standard diameter of the bolt is :

18.0

The diameter of the hub is:

92.5

The bolt circle diameter is :

150.1

The hub length is :

74.0

The shear stress in bolt is calculated to be : 45.027778131399074

Your design is unsafe as the shear stress of bolt exceeds the allowable stress of bolt

ITERATION NO: 5

The standard shaft size in mm is : 50.0

The number of bolts is :

3.25

The standard number of bolts are :

4.0

The diameter of the bolt is : 18.075

The standard diameter of the bolt is :

20.0

The diameter of the hub is:

100.0

The bolt circle diameter is :

164.0

The hub length is :

80.0

The shear stress in bolt is calculated to be : 37.09025943762622

Design based on shear stress of bolt is safe

The width of key is : 16.0

The height of key is : 10.0

The length of the key is : 19.285436893203887

The outside diam and thickness of flange are : 220.0 26.5

The additional parameters of this protected flange coupling are shown below:

The induced shear stress in flange is : 0.45907943756760006

-----DESIGN SPECIFICATIONS-----

Material Name : C10

Factor of safety : 2.6

Allowable stress : 39.61538461538461

Power : 50

no of rotations : 2500

Torque produced : 191000.0

Specifications of shaft and bolt

Diam of shaft : 50.0

Number of bolts : 4.0

Diameter of bolt : 20.0

Hub diameter : 100.0

Bolt circle diameter : 164.0

Hub length : 80.0

Key specifications

length : 19.285436893203887

width : 16.0

height : 10.0

Specifications of flange

Outside diameter : 220.0

Thickness : 26.5

Protected flange coupling parameters

a : 15.0

b : 50.0

c : 7.5

f : 75.0

t1 : 18.85

t2 : 22.0

t3 : 10.0

Based on calculated shear stress of flange ,
Recommended materials for the flange are :

ordinary gray

good gray

high grade gray

SAE32510

NI-Cr

-----Design is over-----

It can be observed that whenever the shear stress of the bolt comes out to be greater than the allowable stress of the bolt material, the program flow shifts back to the excel sheet, takes the next higher value of the diameter of the shaft from the standard size chart and then again runs the same set of formulas to check whether shear stress is lesser than allowable stress of bolt material. If the shear stress comes out to be again greater than the allowable stress, it again follows the same procedure till the time it reaches a safe shear value. For our input parameters, the code undergoes five iterations and finally gets a shear stress value lesser than the allowable stress value of the bolt material, making the design safe.

The next step is to calculate the specifications of the key (length, width and height), based on the stress values found out. Then the flange specifications like outside diameter of the flange and flange thickness are found out for a safe design.

The program code also shows the list of suitable materials for the flange that can be used in the coupling by comparing the induced shear stress in flange to that of the allowable stresses of the list of materials in the excel sheet. The materials having an allowable stress greater than the induced shear stress in flange are displayed to the designer, which makes the task easy of selection of materials for the flange.

The main points are put in a table in a simple easy format so that it becomes easy for the shopfloor supervisor to see the main specifications and accordingly plan, leading to a time efficient optimised production.

Below are the screenshots of the final output python console that have been obtained by running the code:

6. CONCLUSIONS

It can be inferred that with the use of OOP language like Python, the design procedure of protected type flange coupling becomes more user-friendly and the design calculations become more precise and error-free. The final output window shows the significant

details of the design that are needed on the shop floor for the design of couplings and provides clarity to the supervisor. The program code used can be altered depending on the type of coupling needed. The program code is also capable of suggesting a list of suitable materials that might be used for flange by considering the allowable stress of different materials and the induced shear stress in flange. This makes it easy to see and accordingly decide the materials that they can be used for flange based on the design. This activity tends to lead the manufacturing operations towards a more time-efficient, cost-effective and a more reliable and an optimised way of designing machine elements.

7. FUTURE SCOPE

- (a) The code written is a generalised one, and in future, design of several components can be added to this program. Depending on the industry requirement, the designer would choose the appropriate option and accordingly, the code will be able to provide the specifications for that particular machine element.
- (b) The current code is capable of importing data of list of materials, their stresses, the standard size charts, etc from the excel sheet. In future, more parameters can be added to sheets like cost of material, market price, etc. With the help of certain mathematical models, while suggesting the materials for flange materials, the materials with least cost and a high safe stress value will be displayed first in the list so that the designer chooses the topmost material, saving the time for deciding the best material for the flange. Moreover, the available material stocks in inventories can also be added as a parameter.
- (c) Machine learning models can take such program codes to a whole new level. Machine learning models along with Bayesian (statistical) models can be used to predict the failure time of the coupling, provided that the shelf life of the materials are provided in the excel sheets along with their respective failure time. Then the program becomes intelligent enough to decide which material will fail when at what maximum load, though these results would be approximate but they would mean a lot in deciding the suitable materials for the coupling. Highly effective couplings can be produced in such a manner with great ease.

8. REFERENCES

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