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Static & Fracture Analysis and Design Optimization of Drive Shaft in Long Distance Belt Conveyor

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Abstract :In current age of process industry, demand of long-distance belt conveyor is rapidly increasing. For which lot of research works are under process to improve performance & durability of long-distance belt conveyor. For which there is lot of scope available to use high strength material to manufacture belt conveyor mountings & accessories to increase their durability & to reduce maintenance, which directly increase performance of long distance belt conveyor. During our analysis, it was found that there are major failure issues being reported for conveyor's drive shaft. It was also understood that major drive shaft failure was due to incorrect design & wrong material selection for conveyor drive shaft. The objective of this paper is to optimize design& material selection of drive shaft for long distance belt conveyor. We have modified drive shaft designs over conventional shaft design & analyzed these designs with different high strength material materials. We have also concentrated to reduce weight and assembly cost of drive shaft which include drive shaft with Plummer blocks & bearings arrangement. For design optimization of conveyor's drive shaft various design software's i.e. CAD NX and ANSYS have been used. Static Structural analysis performed to find out directional & total deformation and fracture analysis performed to find out values of stress intensity factors & J integral of drive shaft, under defined identical loading & boundary condition. Design Modelling done on CAD NX & Finite Element Analysis done on ANSYS.

Keywords: Conventional Shaft, Drive Shaft, CAD NX, ANSYS, EN8, EN9, EN24

I. INTRODUCTION

Belt Conveyor Equipment, which is used to transport material from one place to another place. These are widely used nowadays in various industries, i.e. Thermal Power Plant; cement Plant, Steel Plant, Aggregates Crushing & Screening plant etc. Long Belt Conveyor used to carry material falling from preceding conveyor via discharge chute or silos etc. to discharge point. It carry material for long distance with higher capacity. Many times due to requirement conveyor capacity increased, due to which more torque need to be transmitted by drive motor to drive shaft of belt conveyor.

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Due to sudden increase in conveyor loading, starting motor torque also increased which leads to failure of drive shaft of belt conveyor. Effective belt tension also increase due to incresement of material loading, for which belt tension on tight side also increase which also increase bending moment at conveyor drive shaft, which lead failure of drive shaft. In Long distance belt conveyor's drive assembly, Drive shaft directly coupled with gearbox via low speed coupling & gearbox input shaft directly coupled with induction motor shaft via high speed coupling. When induction motor started it transmit high value torque to drive shaft through gearbox. Any fluctuation in motor torque due conveyor overloading, change in supply voltage or current to induction motor, leads to failure of drive shaft.

Conveyor drive shaft generally made of EN-8 material. Conventional rolled shaft design followed for shaft manufacturing, drive shaft is mounted in Plummer blocks and bearings arrangement on both sides.

To increase power transmission reduction in moment of inertia required, To reduce shaft weight design modification of shaft done. For which rolled shaft modify to stepped shaft. Stepped shaft further modify with stepped shaft with champers at steps. Which leads to reduction in shaft weight & uniform stress distribution in Shaft Shaft Material also change from existing EN-8 to EN-9 & EN-24, which are more stiffer and higher strength material . These Materials are more specific to design for which shaft strength, stiffness and weight matter in design.

II. SPECIFICATIONS OF DRIVE SHAFT

The Drive shaft mounted in drive pulley which is further rest in Plummer Block & bearing arrangement on both sides. Drive shaft material is generally Structural steel, which change to EN-8 now days. When shaft made of material EN8 fail then replacement of EN8 required with high strength material. In this Paper Existing roller Shaft with Material EN-8 analyzed. For which design modification done with 2 new proposed design & existing material replaced with new high strength materials EN9 & EN24. Selection of shaft diameter done based on Torisional, Bending Moment and Deflection, for Materials EN8, EN9 & EN24. Static structural analysis & fracture analysis performed for all new design & material, under identical loading & boundary conditions.

A. Modeling & meshing of drive shafts

CAD NX used for modeling of drive Shafts, which works on Parametric Feature based module to create Solid Models and Assemblies. Numerical Parameters of Drive shafts are diameter of circle & Length of Line. Geometric Parameter are Tangent to circle, concentric, Horizontal or Vertical etc. Numeric Parameters are Associates with geometric parameters.

In this Paper, we have analyzed, 3 different Shaft Designs which are further analyzed for 3 different types of Materials EN-8, EN-9 & EN-24.

For Static Structural Analysis & Fracture analysis which performed on FEA software- ANSYS for all Total 9 Cases, firstly modeling of drive shaft done then correct mesh pattern performed in ANSYS.

Case-1:- Rolled Shaft with Shaft Material of Construction EN-8
Case-2:- Rolled Shaft with Shaft Material of Construction EN-9
Case-3:- Rolled Shaft with Shaft Material of Construction EN-24
Case-4:- Modified stepped drive shaft with Material of Construction EN-8
Case-5:- Modified stepped drive shaft with Material of Construction EN-9
Case-6:- Modified stepped drive shaft with Material of Construction EN-24
Case-7:- Modified stepped drive shaft with champers cut at steps, with Material of Construction EN-8
Case-8:- Modified stepped drive shaft with champers cut at steps, with Material of Construction EN-9
Case-9:- Modified stepped drive shaft with champers cut at steps, with Material of Construction EN-24

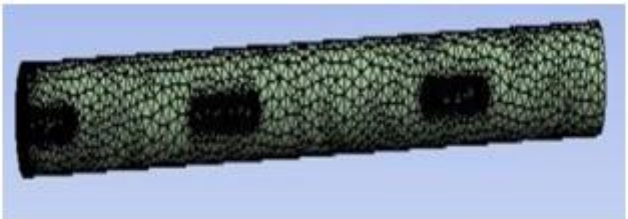

Fig. 1. Existing Shaft Design 1- Modelling & Meshing (For Case 1, Case 2 & Case 3)

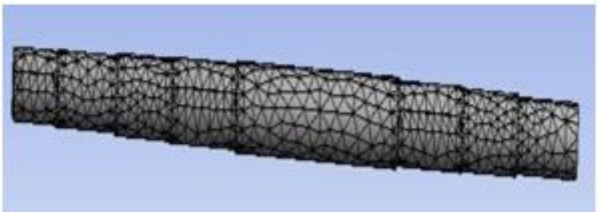

Fig. 2. Modified Shaft Design 2- Modelling & Meshing (For Case 4, Case 5 & Case 6)

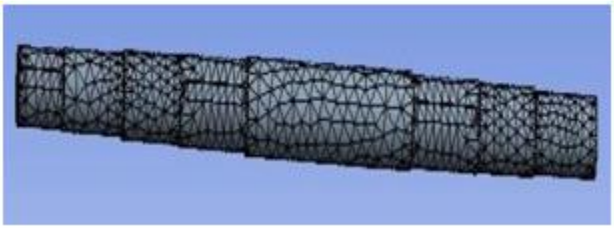

Fig. 3. Modified Shaft Design 3- Modelling & Meshing (For Case 7, Case 8 & Case 9)

B. Properties of Material of construction for Drive Shaft

Table- I: Engineering Properties of Drive Shaft Materials

S. No.	Engineering Data Properties	EN8	EN9	EN24
1	Density (Kg/m^3)	7850	7850	7850
2	Young's Modulus (MPa)	2.0 x 10^5	2.1 x 10^5	2.1 x 10^5
	Poisson's Ratio	0.3	0.3	0.3
	Bulk Modulus (MPa)	1.667 x 10^5	1.75 x 10^5	1.75 x 10^5
	Shear Modulus (MPa)	7.6923 x 10^4	8.0769 x 10^4	8.0769 x 10^4
3	Co-efficient of Thermal Expansion	11 C^{-1}	11 C^{-1}	10 C^{-1}
4	Isotropic Secant Co-efficient of Thermal Expansion Reference Temperature (˚C)	20	20	20
5	Ultimate Tensile Strength (MPa)	660	750	850
6	Yield Strength (MPa)	465	570	650

C. Geometry specification and Boundary Conditions

Table- II: Geometric Specification & Boundary Conditions

Descriptions	For Case-9
Remote force to be applied on shaft	74894.08 N
Materials	EN24
Length X	170 mm
Length Y	170 mm
Length Z	2120 mm
Volume	44407162.87mm³
Mass	347.74 kg
Centroid X	-2.7447e-005 mm
Centroid Y	-0.67348 mm
Centroid Z	-1661 mm
Moment of Inertia Ip1	2.0688e+009 kg·mm²
Moment of Inertia Ip2	2.069e+009 kg·mm²
Moment of Inertia Ip3	1.9413e+007 kg·mm²
Nodes	8564
Elements	5071

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III. RESULT AND ANALYSIS

A. Static Structural Analysis of drive shafts

Static Structural analysis performed to know shape deformation under identical loading & boundary conditions. In this paper directional deformation & total deformation calculated to find out optimized design based on deformation for all 9 cases. From FEA deformation results lowest Directional & Total deformation value are find out for Case-9, which shows that modified shaft design 3 (stepped shaft with champers) with material EN24is optimized design under identical loading & boundary condition.

Table- III: Static Structural Analysis Directional Deformation

Sr. No.	Case Study	Design Description		Directional Deformation	
		Design	Material	Minimum (m)	Maximum (m)
1	Case-1	Design-1	EN-8	-8.12E-03	8.12E-03
2	Case-2	Design-1	EN-9	-8.12E-03	8.12E-03
3	Case-3	Design-1	EN-24	-7.16E-03	7.20E-03
4	Case-4	Design-2	EN-8	-7.23E-03	7.13E-03
5	Case-5	Design-2	EN-9	-7.23E-03	7.13E-03
6	Case-6	Design-2	EN-24	-6.97E-03	6.54E-03
7	Case-7	Design-3	EN-8	-8.93E-04	5.05E-04
8	Case-8	Design-3	EN-9	-8.93E-04	5.07E-04
9	Case-9	Design-3	EN-24	-7.96E-04	5.04E-04

Table- IV: Static Structural Analysis Total Deformation

Sr. No.	Case Study	Design Description		Total Deformation	
		Design	Material	Minimum (m)	Maximum (m)
1	Case-1	Design-1	EN-8	1.40E-05	1.55E-03
2	Case-2	Design-1	EN-9	1.40E-05	1.55E-03
3	Case-3	Design-1	EN-24	3.79E-05	1.45E-03
4	Case-4	Design-2	EN-8	1.22E-05	1.35E-03
5	Case-5	Design-2	EN-9	1.22E-05	1.35E-03
6	Case-6	Design-2	EN-24	1.36E-05	1.35E-03
7	Case-7	Design-3	EN-8	2.86E-06	7.41E-04
8	Case-8	Design-3	EN-9	2.86E-06	7.41E-04
9	Case-9	Design-3	EN-24	2.66E-06	7.34E-04

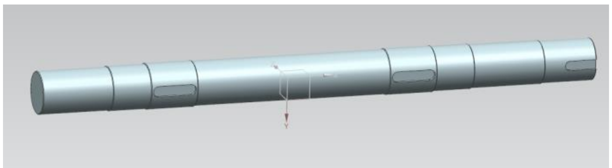

Fig. 4. Modified Shaft Design 3 with Materials EN24, For Case 9

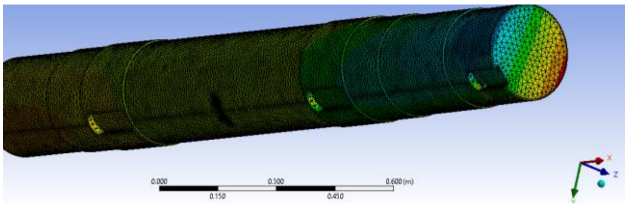

Fig. 5. Modified Shaft Design 3 with Materials EN24 Static Structural Analysis-Directional Deformation

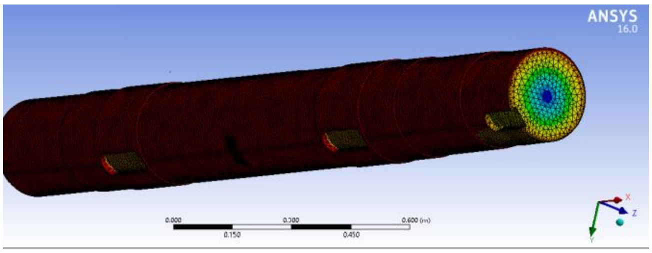

Fig. 6. Modified Shaft Design 3 with Materials EN24 Static Structural Analysis-Total Deformation

B. Fracture Analysis of drive shaft

Fracture analysis performed to know stress distribution in drives shaft under identical loading & boundary conditions. In this paper, for fracture analysis stress intensity factors value for SIFS K1, SIFS K2, SIFS K3 & J-Integral value have been calculate for all 9 cases of drives shaft. From fracture analysis results its shows that value of SIFS K1, SIFS K2, SIFS K3 & J Integral find lowest for case 9, which shows that modified shaft design 3 (stepped shaft with champers) with material EN24 is optimized design under identical loading & boundary condition.

Table- V: Fracture Analysis SIFS K1

Sr. No.	Case Study	Design Description		SIFS K1	
		Design	Material	Minimum Pa.mm^(0.5)	Maximum Pa.mm^(0.5)
1	Case-1	Design-1	EN-8	-1.71E+08	3.99E+07
2	Case-2	Design-1	EN-9	-1.71E+08	3.93E+07
3	Case-3	Design-1	EN-24	-1.58E+08	3.91E+07
4	Case-4	Design-2	EN-8	-2.16E+07	1.94E+07
5	Case-5	Design-2	EN-9	-2.16E+07	1.94E+07
6	Case-6	Design-2	EN-24	-2.16E+07	1.94E+07
7	Case-7	Design-3	EN-8	-2.33E+06	1.11E+07
8	Case-8	Design-3	EN-9	-2.33E+06	1.11E+07
9	Case-9	Design-3	EN-24	-1.96E+06	1.02E+07

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Table- VI: Fracture Analysis SIFS K2

Sr. No.	Case Study	Design Description		SIFS K2	
		Design	Material	Minimum	Maximum
				Pa.mm^ (0.5)	Pa.mm^ (0.5)
1	Case-1	Design-1	EN-8	-3.12E+07	4.19E+07
2	Case-2	Design-1	EN-9	-7.27E+07	3.36E+07
3	Case-3	Design-1	EN-24	-8.27E+06	3.24E+06
4	Case-4	Design-2	EN-8	-8.45E+06	3.20E+06
5	Case-5	Design-2	EN-9	-8.43E+06	3.20E+06
6	Case-6	Design-2	EN-24	-8.43E+06	3.20E+06
7	Case-7	Design-3	EN-8	-4.17E+06	1.44E+06
8	Case-8	Design-3	EN-9	-4.17E+06	1.44E+06
9	Case-9	Design-3	EN-24	-1.15E+06	1.17E+06

Table- VII: Fracture Analysis SIFS K3

Sr. No.	Case Study	Design Description		SIFS K3	
		Design	Material	Minimum	Maximum
				Pa.mm^ (0.5)	Pa.mm^ (0.5)
1	Case-1	Design-1	EN-8	-2.75E+07	4.32E+07
2	Case-2	Design-1	EN-9	-2.67E+07	3.29E+07
3	Case-3	Design-1	EN-24	-2.00E+07	1.68E+07
4	Case-4	Design-2	EN-8	-8.93E+06	1.77E+06
5	Case-5	Design-2	EN-9	-8.93E+06	1.77E+06
6	Case-6	Design-2	EN-24	-8.93E+06	1.77E+06
7	Case-7	Design-3	EN-8	-7.31E+05	3.50E+05
8	Case-8	Design-3	EN-9	-7.31E+05	3.50E+05
9	Case-9	Design-3	EN-24	-3.40E+05	3.19E+05

Table- VIII: Fracture Analysis J-Integral

Sr. No.	Case Study	Design Description		J-integral	
		Design	Material	Minimum	Maximum
				J/m2	J/m2
1	Case-1	Design-1	EN-8	-4.70E+05	1.26E+07
2	Case-2	Design-1	EN-9	-6.20E+04	1.38E+07
3	Case-3	Design-1	EN-24	-1.10E+04	8.24E+06
4	Case-4	Design-2	EN-8	-5.08E+05	3.05E+06
5	Case-5	Design-2	EN-9	-5.08E+05	3.05E+06
6	Case-6	Design-2	EN-24	-3.08E+05	3.05E+06
7	Case-7	Design-3	EN-8	-4.20E+05	2.40E+06
8	Case-8	Design-3	EN-9	-4.20E+05	2.40E+06
9	Case-9	Design-3	EN-24	-4.58E+03	1.69E+04

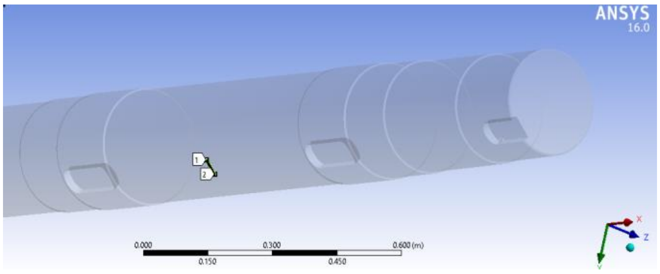

Fig. 7. Modified Shaft Design 3 with Materials EN24 Fracture Analysis-SIFS K1

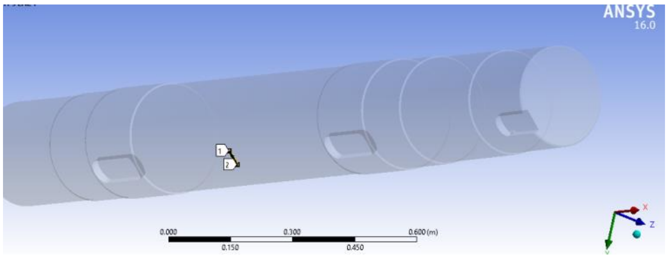

Fig. 8. Modified Shaft Design 3 with Materials EN24 Fracture Analysis-SIFS K2

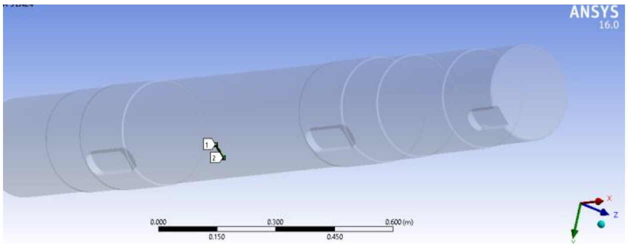

Fig. 9. Modified Shaft Design 3 with Materials EN24 Fracture Analysis-SIFS K3

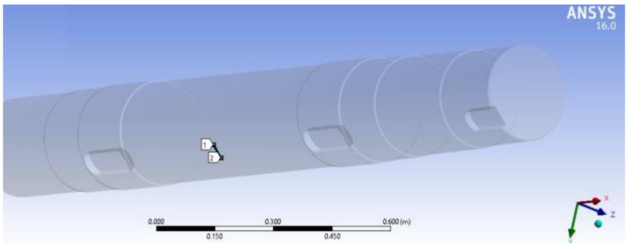

Fig. 10. Modified Shaft Design 3 with Materials EN24 Fracture Analysis-J Integral

IV. CONCLUSION

The static structural analysis and fracture analysis results are tabulated for all 9-Cases in last section, from where, Following are our conclusions:-

1. From the static structural analysis results its shows lowest directional deformation value resulted for Case9
2. From the static structural analysis results its shows lowest total deformation value resulted for Case 9.
3. From the fracture analysis results for value of SIFS K1 its shows lowest K1value resulted for Case 9.

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4. From the fracture analysis results for value of SIFS K2 its shows lowest K2value resulted for Case 9.
5. From the fracture analysis results for value of SIFS K3 its shows lowest K3value resulted for Case 9.
6. From the fracture analysis results for value of J-Integral its shows lowest J-Integral value resulted for Case 9.

From above it's concluded that the Case 9 (Design 3 with material EN 24) is optimized design for both static structural analysis & Fracture Analysis.

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