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DESIGN AND ANALYSIS OF PERMANENT MAGNET DIRECT DRIVE FOR HOIST OF 1 T ELECTRIC OVERHEAD TRAVELLING CRANE

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ABSTRACT – The conventional hoisting mechanism used in industries consists of complicated four way transmission system of motor- gearbox -coupling- drum and rope assembly. Which is subjected to frequent failures due to failure of any of these above mentioned components .Here we have proposed a novel concept of implementing the Permanent Magnet Direct Drive (PMDD) in hoisting mechanism for 1 T Electric overhead Travelling(EOT) Crane. Implementation of PMDD can completely eliminate use of Gearbox; which we need for high torque and low RPM. PMDD is designed and analyzed for successful implementation in hoisting mechanism. The Designed and Analyzed PMDD will be able to give the high torque at low RPM for 1 T EOT crane. The PMDD offers many other significant advantages over conventional mechanism like almost zero maintenance, no lubrication, physical Isolation, less vibration, more reliability less power consumption.

INTRODUCTION

The conventional mechanism used in EOT crane is consisting of Motor- Gearbox- coupling- drum and rope assembly. This research has been carried to because of the frequent failures in conventional hoisting mechanism like failure of gearbox, failure of coupling, frequent lubrication and maintenance, excessive vibration and excessive noise. Due to vibration the parts may deteriorate slowly and ultimately leads to failure It will lead to a great monetary loss too especially in railway yards, steel industries etc. In order to accommodate the frequent failures; the shop floor must need excess inventory which may not lead to stop the working of EOT crane for various crucial operations.

Figure 1. Conventional Hoisting Mechanism

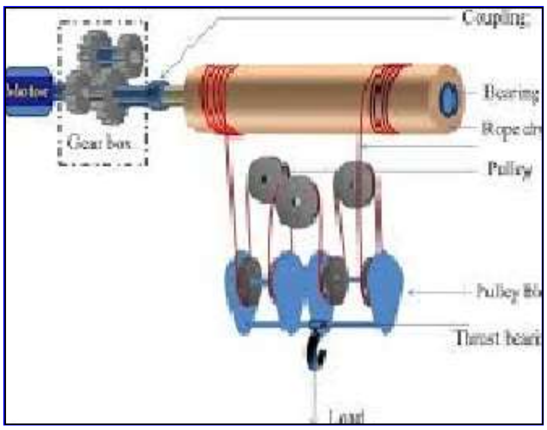
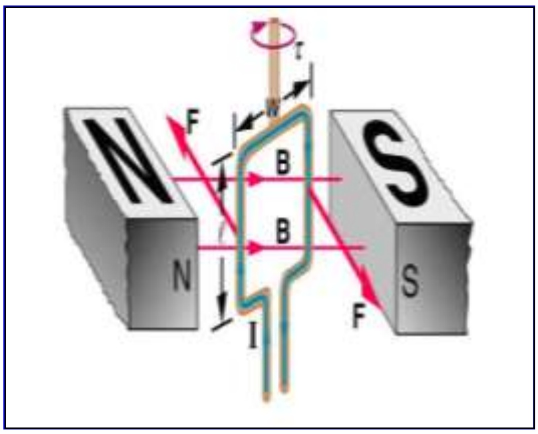


Figure 2. Proposed Principle for Hoisting Mechanism



The novel idea of the Permanent magnet motor drive to implement in hoisting mechanism is inspired by the concept of using the natural, free and sustainable energy of Permanent Magnets

(PM). With innovation in the field of PM and availability of magnetic materials like Samarium-cobalt (Sm-Co) and Neodium-iron-boron (Nd-Fe-B) are the PM which offers very good Properties for PM and gives excellent high temperature performance.

After doing the thorough literature survey PMDD was identified as the best suitable option to use in hoist. After that Stator and Rotor which are the most important part of the PMDD is designed and analyzed to use in hoist of 1 T EOT crane. We may use the designed and analyzed PMDD to replace the gearbox without affecting the performance. This will lead to more significant advantages in a long run. We are able to get the higher torque at lower RPM with designed stator and rotor assembly of PMDD. Due to that we can totally eliminate the conventional gearbox used in hoisting mechanism to get the higher torque and required less RPM [1].

The remainder of this paper is organized as follows: Section 2 briefly presents relevant literature survey. Section 3 explains the design of hoist for 1 T hoist. Section 4 provides the analysis of PMDD. Section 5 concludes the paper.

LITERATURE SURVEY

A thorough literature survey has been done to figure out the most suitable alternative for conventionally used hoisting mechanism and to replace the gearbox. Few alternatives studied are Magnetic Gears, Fluid Coupling and PMDD with Variable Frequency Drive.

Magnetic gear (MG) offers significant advantages of reduced acoustic noise, minimum vibration, free from maintenance, improved reliability, inherent overload protection, and physical isolation. The concept of magnetic gearing into the permanent-magnet machines, leads to achieve low-speed high-torque direct-drive operation. Low utilization and poor performance of ferrite permanent magnet (PM) material made it impossible to be widely used in industry. Until the high-performance neodymium iron born (Nd-Fe-B) these converted MGs simply replaced the slots and teeth of iron core by N-poles and S-poles of PMs, respectively. Unlike the converted MGs, the Coaxial MG has a higher torque density, because all the PMs simultaneously contribute to torque transmission. In view of the coaxial structure, the CMG can be artfully integrated with a high-speed outer rotor PM brushless machine to constitute a composite electrical machine named as the magnetic-geared permanent-magnet (MGPM) machine, which can achieve low-speed high-torque driving while providing high torque density. The MPG with six magnetic planet gears exhibits nearly 100kNm/m^3 [1, 2, and 3].

Figure 3. Magnetic Gear

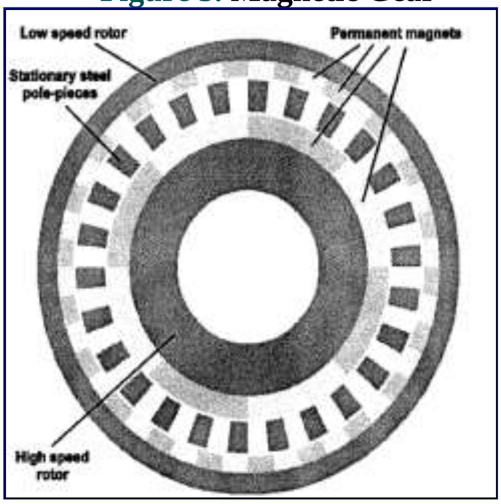
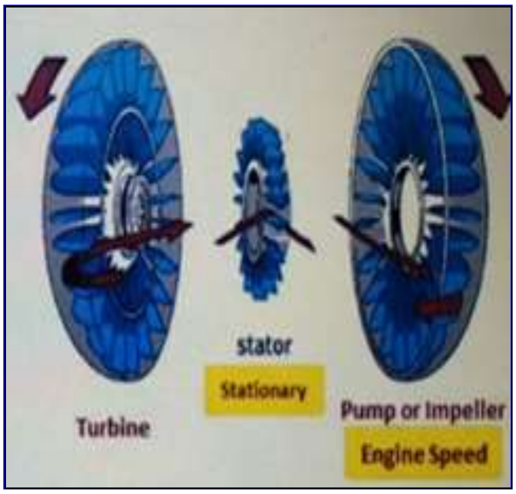


Figure 4. Fluid Coupling



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A hydrodynamic or "hydrokinetic" device called a fluid coupling or hydraulic coupling is used to transfer rotating mechanical power. It is also widely used in maritime and industrial machine drives, where regulated start-up at different speeds is essential to prevent shock loading of the power transmission system. [4].

PMDD with Variable Frequency Drive is studied for the proposed concept and which is proved to be the best suitable for hoisting mechanism to get high torque at low RPM. The key concept is to eliminate the four part transmission structure of the shaft, reducer, drum, and motor to realize the direct drive in order to address the problems in the crane industry [5-7].

There is no intermediate mechanical transmission in motor drive technology. Both the linear motion component with a linear motor serving as the core drive element and the rotary motion component with a torque motor serving as the core drive element are applications of direct drive technology.

Figure 5. PMDD

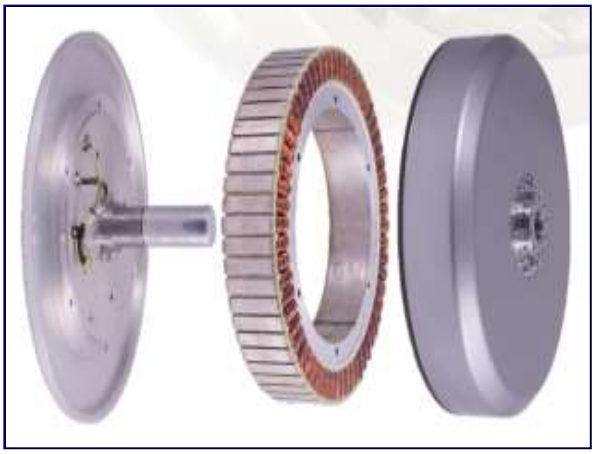
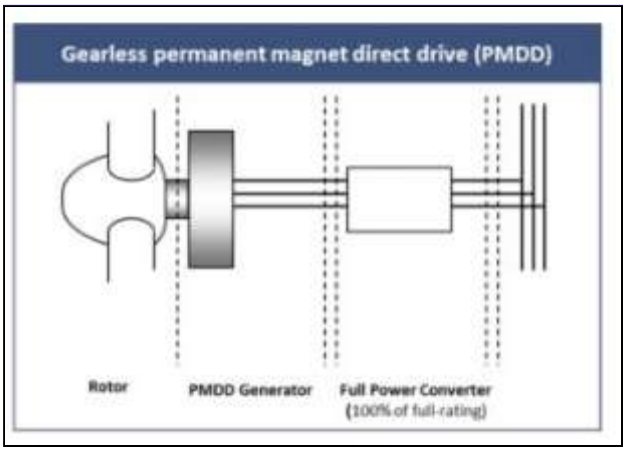


Figure 6. Line Diagram PMDD



Currently, elevators, machine tools, belt machines, mines, wind power generation, and other industries employ direct drive technology extensively. It is more usual to obtain direct motor drive by doing away with the intermediary transmission as low speed and high torque motor technology continues to advance.

DESIGN OF PMDD USED IN HOIST FOR 1 T EOT CRANE

Permanent Magnet Direct Drive Motor is attempted to design here. The basic variables used in the Design Method are [8-10];

Table 1. Variables used in the Design

Design Variables		Corresponding basic variables	
d	Air gap diameter	d	Air gap diameter
l	Stator length	l	Stator length

h_s	Slot height	h_s	Slot height
τ_P	Pole pitch	τ_P	Pole pitch
J_B	Current density	J_B	Current density
$B_{\delta 0}$	Peak air gap flux density	h_m	Magnet height
B_{d0}	Peak teeth flux density	b_d	Tooth width

Constant and fixed relations		Corresponding basic variables	
B_{ys}	Peak Stator yoke flux density	h_{ys}	Stator yoke height
B_{yr}	Peak rotor yoke flux density	h_{yr}	Rotor yoke height
h_{s1} = 1 mm	Tooth tip height	h_{s1}	Tooth tip height
h_{s2} = 4 mm	Slot wedge height	h_{s2}	Slot wedge height
b_{s1} = 3 mm	Slot Opening	b_{s1}	Slot opening
h_i = 1 mm	Insulation Thickness	h_i	Insulation Thickness
$\delta = 0.001$ d	Mechanical Air gap	δ	Mechanical Air gap
q = 1	No. of slots per pole	τ	Slot Pitch

	& phase		
b_m=0.7Ƭp	Magnet Width	b_m	Magnet Width

Design Equations [8-10]

To determine number of poles,

$$N = \frac{120 \times f_s}{P} \quad (1)$$

$$\text{where, } N = RPM$$
$$f_s = frequency$$
$$P = Number\ of\ poles$$

The diameter and pole pitch, determine the pole pairs,

$$p = \frac{\pi d}{2.\tau_p} \quad (2)$$

$$\text{where, } p = Number\ of\ pole\ pairs$$
$$\tau_p = Pole\ pitch, m$$
$$d = Air\ gap\ diameter, m$$

The total number of slots on stator is

$$Q = 2\,p\,m\,q \quad (3)$$

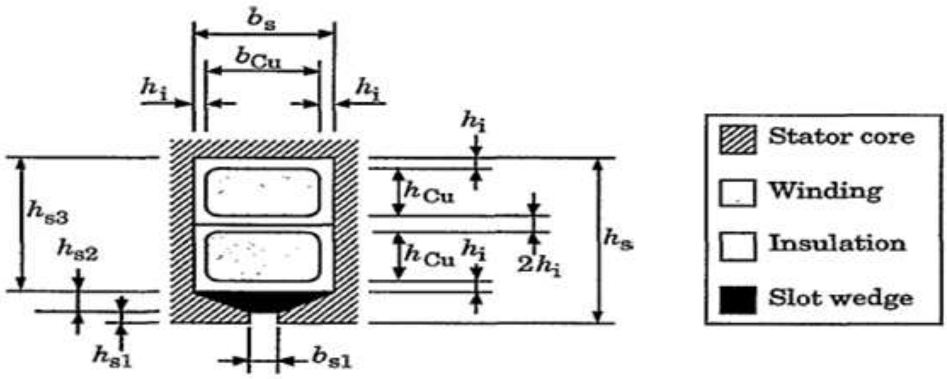
$$\text{where, p = number of pole pairs}$$
$$\text{q = number of slots per pole}$$
$$\text{m = number of phase}$$

The Slot Pitch is;

$$\tau = \frac{\tau_p}{m\,q} \quad (4)$$

The slots and the two layer windings are shown in Figure: 7. The slot is described by its depth hs and its width bs.

Figure 7. Basic Variables in Design



The slot width can be calculated from the slot pitch Ꞇ and tool width b_d as:

$$b_s = \tau - b_d \qquad (5)$$

$$where, b_s = slot \ width$$
$$b_d = tooth \ width$$
$$\tau = slot \ pitch$$
$$h_s = slot \ depth$$

The slot opening b_{s1} is assumed to be 3mm, the tooth tip height h_{s1}= 1mm, and the slot wedge height h_{s2}= 4mm. The winding height is h_{s3}

$$h_{s3} = h_s - h_{s1} - h_{s2} \qquad (6)$$

The conductor height hcu and width bcu are determined by the winding height, slot width and the coil insulation thickness hi;

$$h_{cu} = \frac{h_{s3} - 4h_i}{2} \qquad (7)$$

$$h_{cu} = conductor \ height$$
$$h_i = insulation \ height$$

$$b_{cu} = b_s - 2h_i \qquad (8)$$

, $$b_{cu} = conductor \ width$$

For a three phase machine for which the magnet cost per torque should be kept low, the ratio of magnet width to pole pitch should be between 0.6 and 0.9 (Lampola et. Al 1996a). In the proposed design the magnet width is kept at 0.7 times the pole pitch, i.e.,

$$b_m = 0.7 \ \tau_p \qquad (9)$$

$$b_m = magnet \ width$$

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As the winding is a full pitch winding, the winding pitch W is;

$$W = \tau_p \tag{10}$$

The end winding length is assumed to be

$$l_b = 2\ W \tag{11}$$

The Equivalent core length is approximated by

$$l_e = l + 2\ \delta \tag{12}$$

The useful iron length is

$$l_u = k_{Fes} l \tag{13}$$

$where, k_{Fes} = iron$ fill factor

The frequency at rated speed is

$$f = p\ \mathrm{n}_N \tag{14}$$

$where,\ p = pole$ pair

The iron gap should be small to minimize the amount of Permanent Magnet needed .The mechanical stiffness and the thermal expansion limits the minimum air gap which can be used is,

$$\delta = 0.001\ d \tag{15}$$

The slot opening is narrow compared with the air gap, so carter factor will be 1.The outer diameter of the stator dse

$$d_{se} = d + 2\ h_s + 2\ h_{ys} \tag{16}$$

Approximate total length of the stator

$$l_{total} = l + 3\ W \tag{17}$$

Calculated Dimensions

By using the above dimensions for we do get following values;

Table 2. Calculate Dimensions

Design parameter	Calculated value	Design parameter	Calculated value
N	15 – 20 rpm	lb	20 mm

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P	32 nos.	le	75 mm
Pp	16 nos.	dse	485mm
τ_p	10 mm	hs3	20mm
τ	3.33 mm	hcu	8 mm
bs1	1mm	bcu	0. 165 mm
hs1	4mm	bm	7 mm
w= τ_p	10 mm		

Modeling of Stator Rotor as per the Calculate Dimensions

Modeling is done in fusion i360 for stator, rotor and Assembly of stator and Rotor.

Figure 8. Detail Drawing of a Stator

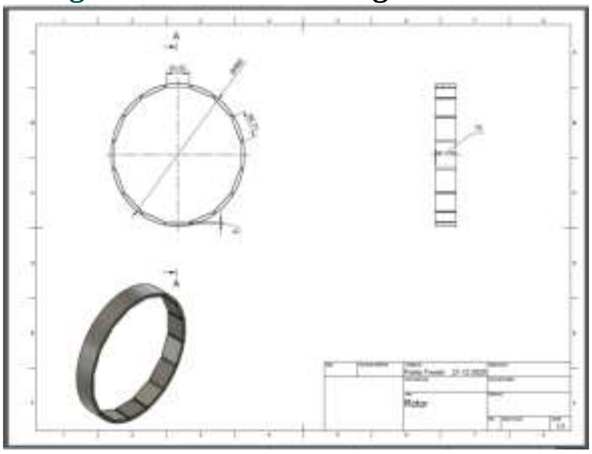


Figure9. Detail Drawing of Rotor

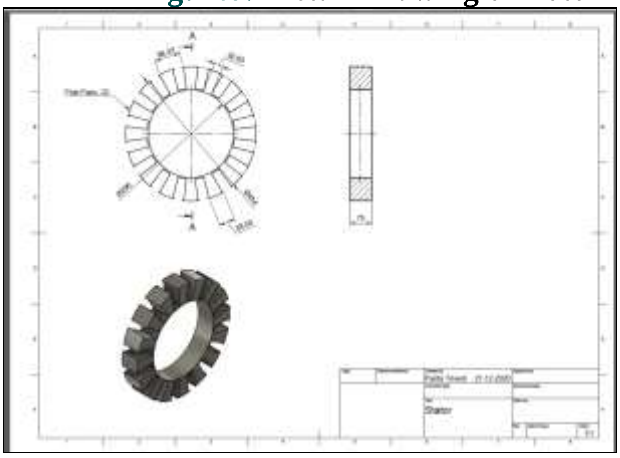
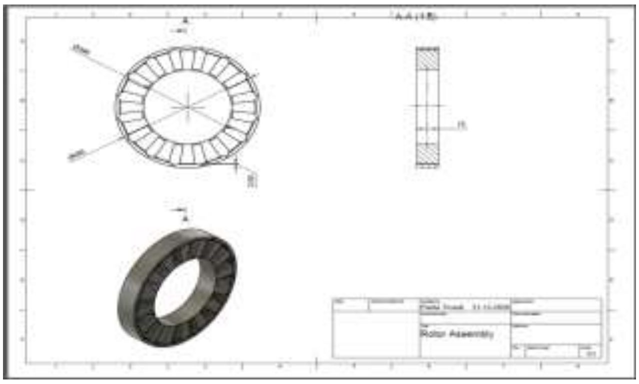


Figure10. Assembly of Stator and Rotor



ANALYSIS OF PMDD

Analysis is done in Ansys workbench 2019 R3 **Meshing : Meshing with Nodes: 17350 Elements: 4585**

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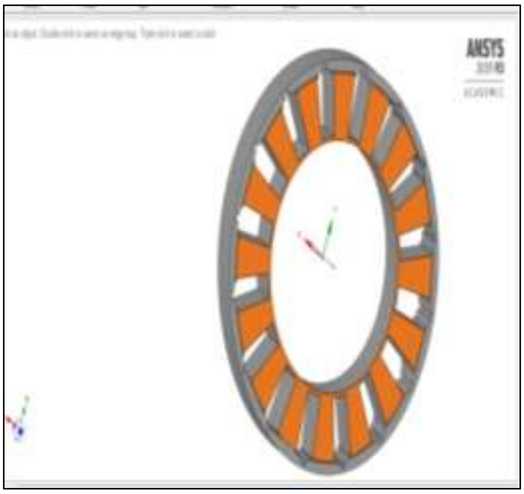
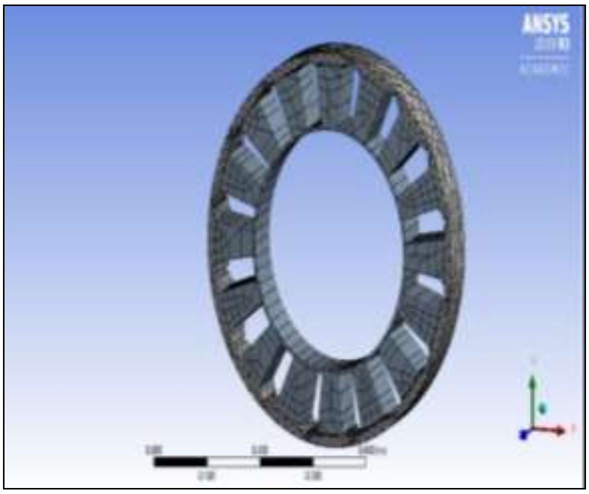
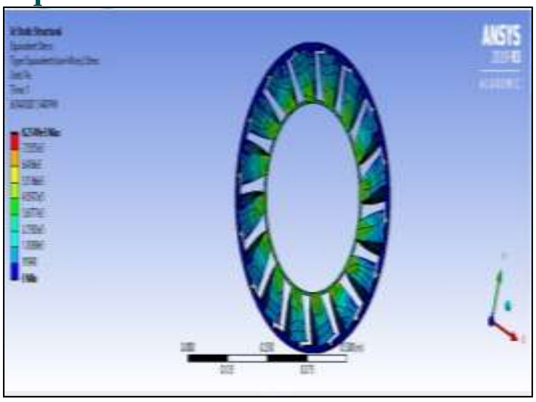
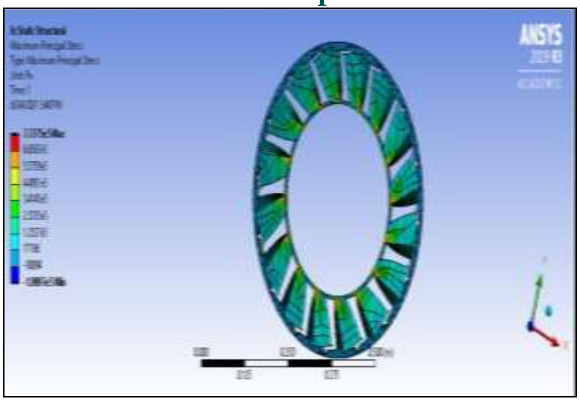




Equivalent stress

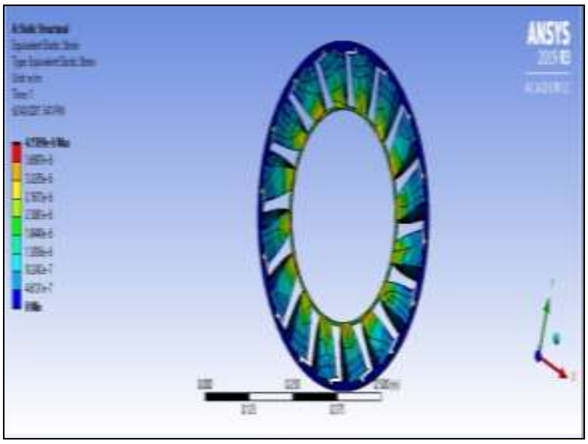
Maximum Principle Stress

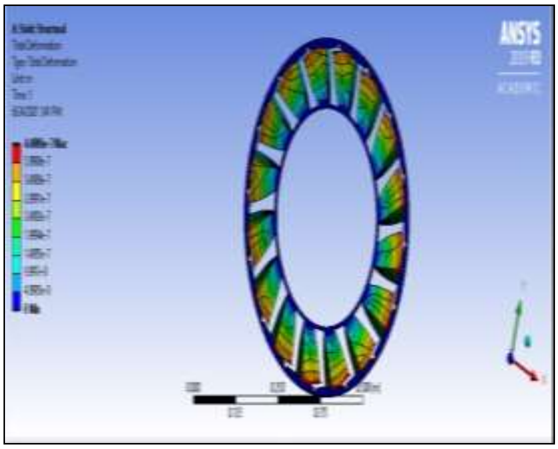




Equivalent Elastic strain

Deformation





Summary of Analysis

Table 2. Summary of Analysis in Ansys

Type of Analysis	Structural	Unit
Equivalent Von-Mises Stress	8.27×10^{5}	Pa
Maximum Principal stress	7.73×10^{5}	Pa
Equivalent Elastic Strain	4.15×10^{-6}	m/m

Total Deformation	4.49×10^{-7}	m

Comparison diagram of failure rate of the Lifting Mechanism

Failure rate of Conventional mechanism and the proposed mechanism is given as below [11]

Table 3. Failure rate comparison

SN	Part	Traditional Hoist		Proposed Hoist	
		Failure Rate %	Main Failure	Failure Rate %	Main Failure
1	Gearbox	22	Broken teeth, poor oil quality, insufficient oil quantity, oil leaks, gear heating, and vibration	0	0
2	Motor	13	Motor heating, a short circuit, a cracked installation base, a failed fan, etc.	5	Motor heating, a short circuit, a cracked installation base, a failed fan, etc.
3	Shaft	6	Fractures, joint deformity, and loose joints	0	0
4	Coupling	20	A loose lubrication nut, an unusual sound, wear, and deformation	0	0
5	Brake	18	Deformation loosely mounted brake wheel. unusual braking torque mechanisms and a decline in braking torque	7	Bolt loosening, oil pipe leakage, spring ageing, etc.
6	Rope	5	rope fracture, skip rope groove, and rope brake	5	rope fracture, skip rope groove, and rope brake
7	Lifting control system	16	Older electric components, unsecured terminals, and burned inverter	16	Older electric components, unsecured terminals, and burned inverter
Total		100		33	

According to the above table, the suggested lifting mechanism has a failure rate that is 67 percent lower than the traditional lifting mechanism, which accounts for 45 percent of the failure rate of the entire crane.

Cconclusion

This paper reports the first attempt to implement the newer concept of Permanent Magnet Direct Drive motor to use in hoist used for 1 Tonnage Electric overhead travelling crane. PMDD motor is designed and analyzed for 1 T EOT crane. For further research we may go for higher capacities of EOT crane, Tower crane and other material handling equipments.

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REFERENCES

[1] K. Atallah and D. Howe, "A Novel High-Performance Magnetic Gear", IEEE TRANSACTIONS ON MAGNETICS, VOL. 37, NO. 4, JULY 2001
[2] Andreas Penzkofer and Kais Atallah. "Magnetic Gears for High Torque Applications" , IEEE TRANSACTIONS ON MAGNETICS, VOL. 50, NO. 11, NOVEMBER 2014.
[3] X. Li, K.-T. Chau et.al., "COMPARISON OF MAGNETIC-GEARED PERMANENT-MAGNET MACHINES", Progress In Electromagnetics Research, Vol. 133, 177-198, 2013.
[4] C. Pease,H.S. Wijesinghe, et.al, Magnetic and Hydrodynamic Torques:Dynamics of Superparamagnetic ,Journal of Magnetism and Magnetic Materials, https://doi.org/10.1016/j.jmmm.2018.07.014
[5] Gieras JF. Permanent magnet motor technology: design and applications. CRC Press; 2009 Aug 26.
[6] Cui JG, Xiao WS, Zhao JB, Lei JX, Wu XD, Wang ZG. Development and application of low-speed and high-torque permanent magnet synchronous motor. In: Applied mechanics and materials, vol. 229. Trans Tech Publications; 2012. p. 888–94.
[7] Guo Q, Zhang C, Li L, Zhang J, Wang M. Maximum efficiency per torque control of permanent-magnet synchronous machines. Appl Sci 2016 Dec 12;6 (12):425.
[8] Y. Alexandrova,"Permanent Magnet Synchronous Generator Design Solution for Large Direct-Drive Wind Turbines.
[9] Design of Direct-driven Permanent-magnet Generators for Wind Turbines by Anders Grauers.
[10] D. C. Hanselman, Brushless Permanent Magnet Motor Design. USA: McGrawHill, 1994.
[11] ABB, 1991. Product Catalogue from ABB Motors, Sweden, 77 p.