MODELLING AND FABRICATION OF LINEAR MAGNETIC CLIMBER FOR VISUAL INSPECTION OF MAGNETIC METAL SURFACES IN INDUSTRIES

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Key Words: Modelling & Fabrication, Linear Magnetic Climber, Visual Inspection, Upper Platform and Lower Platform

ABSTRACT

Most of the process industries use larger ducts and pipes for transfer of solid, liquid and gaseous materials. However due to corrosion or improper welding the pipes or ducts gets damaged. Inspection of larger size ducts and chimneys takes lot of time and effort due to lesser accessibility in terms of size and hurdles. We can use wheel-based movers for horizontal surfaces but it is not possible for vertical surfaces.

As a part of my project work, Linear Magnetic Climber is modelled and fabricated for Visual Inspection of Magnetic Metal Surfaces (Mild Steel or Carbon Steel) in Industries.

Electro magnets, Lead Screw & nut and Rectangular box motor are used to make the machine capable of travelling on vertical surfaces having good magnetic properties. This machine can make video of path it is travelling and camera can transfer data to mobile phone

Advantages;

- Requires less man power to operate
- No accidents as no manual climbing or descending is involved
- Low cost of inspection
- Low Investment as it is indigenous technology
- Easy to transport as it hardly requires mobile phone against large computer set up to see the visuals

LITERATURE SURVEY

Wall Climbing Crawlers for Nondestructive Testing – Tarraq P. Sattar (2021)

Inspection is done either while plant is on its maintenance run or if any major problem is encountered in plant.

There are two types major issues which causes problem in chimney,

- External attack
- Internal attack

External attack

This is a slow process and for the chimneys which are insulated, it's hardly any concern for such chimneys. There are pollutants leaving out of chimney which contain acidic flue gases.

These gases react with the moisture in the air surrounding the chimney and when reacted, it can form acid and get settled on the surface on the chimney.

Internal attack

Internal attack on chimneys are really risky and it shall be identified and cured.

There are two types of internal attacks on chimney,

- Abrasion
- Corrosion

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Abrasion

Abrasion mostly occurs in power plants which used solid fuels for combustion. Abrasion with corrosion can quickly erode the steel and has to be identified quickly.

Corrosion

In the thermal power plant, if the content of sulphur is higher in fuel used in combustion process, the gases leaving outside the chimney will be high sulphur and will result in high sulphur condensation on the chimney. Sulphur acid is the most known acid which corrodes the steel quickly.

Latest Measures to Keep Chimneys in Step with Plant Changes – Vladier cavin (2015)

Fall accidents are seen in almost every industry while working or inspection at heights. While inspection of big vertical ducts, it involves huge risk on the person of inspection team.

Sometimes the victims forget, neglect doesn't wear the safety instructions and perform the task. In absence of safety measures, a small mistake will result in loose in life by falling on the ground from bucket. There are many ways of investigating ducts by using drones which got quite popular for inspecting at elevations. But drones are limited as they can't reach some places and so their application in inspections becomes limited.

There are different cases which causes fall hazard and discussed below,

- Personal protective equipment not available
- Personal protective equipment available but not wearing
- Wearing Personal protective equipment, but not using
- Using Personal protective equipment incorrectly
- Using Personal protective equipment, but Personal protective equipment failed
- Personal protective equipment not applicable

Personal protective equipment includes harnesses, safety belts, lifelines, and respirators.

INTRODUCTION

For the inspection of industrial infrastructures, thermal power plant ducts, chimneys and various high-altitude place as shown in figure (1.1) which can be dangerous for the person inspecting.

Fig (1.1) inspection of chimney

Thermal power plant has enormous amount of ducts used to transferring heat, flue gas, etc., these ducts and large diameter pipes can be damaged over long term use. Ducts and pi[pes are required to undergo inspection to avoid reduction of efficiency, some ducts and pipes are big enough to provide a man hole for an inspector to enter inside for inspection but some ducts and pipes are really small in which a person cannot enter and it has hard to inspect such pipes. Such pipe is as shown in figure (1.2).

Fig (1.2) pipe inspection

For inspecting such ducts made of magnetic materials like carbon steel and mild steel as well as high altitude and needs vertical climbing, It is planned to model and fabricate a magnetic climber as shown in figure (1.3).

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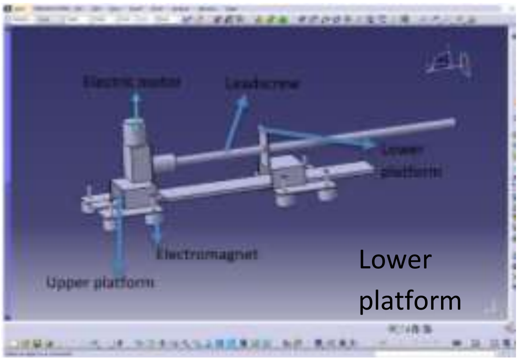

Fig (1.3) magnetic climber

METHODOLOGY:

Upper Platform: Supports 4 number of electromagnets, motor and camera are mounted on upper platform

Lower Platform: Supports 4 number of electromagnets and lead screw nut is mounted on lower platform

Leadscrew: It is mounted to the electric motor of upper platform via flexible coupling and nut to lower platform. When motor is made rotate clockwise direction, it will pull the lower platform up and wise versa

Electromagnet: It is mounted on both upper and bottom platform as shown above in figure (1.3) they will hold metallic surface upon powering them.

Ascending and Descending: Initially upper platform electromagnets are engaged on metal surface and lower platform is retracted by clockwise rotation of screw and then lower platform electromagnets are engaged and upper platform electromagnets are engaged. The process continues for ascending. The same process can be used for descending in reverse pattern

CALCULATIONS

Calculation of Torque and Power while Upper Platform is Ascending

Mass of motor (m1) = 0.1Kg

Mass of upper platform base plate & motor support plate (m2) = 0.125Kg

Mass of each magnet m_m = 0.05Kg

Mass of upper platform magnets (m3) =4 x 0.05 = 0.2Kg

Mass of upper platform springs and screws (m4) = 0.04Kg

Mass of Camera (m5) = 0.06Kg

Mass of cable (m6) = 0.125Kg

Mass of Threaded Rod (m7) = 0.1Kg

Total Mass to be lifted while upper platform is ascending

(m_u) = m1+m2+m3+m4+m5+m6+m7

= 0.1 + 0.125 + 0.2 + 0.04 + 0.06 + 0.125 + 0.1 = 0.75 Kg

Mean Thread Diameter (dm) = 7mm

= 0.007m

Lead (L) = 8mm

= 0.008m

Gravity (g) = 9.81 m/s^2

Load to be lifted while upper platform ascending (Fu) = m_u x g

= 0.75 x 9.81 = 7.3575N

Coefficient of Friction based on table 5.1 (μ) = 0.19

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Screw Metal	Nut Metal			
	Steel	Bronze	Brass	Cast iron
Dry Steel	0.15-0.25	0.15-0.23	0.15-0.19	0.15-0.25
Machine Oiled Steel	0.11-0.17	0.10-0.16	1.10-0.15	0.11-0.17
Bronze	0.08-0.12	0.04-0.06	not available	0.06-0.09

Table (5.1) Coefficient of Friction

Lifting Torque while upper platform is ascending (T_{Ru})

= (Fu x dm/2) x ((L+Л x μ x dm)/(Л x dm - μ x L)

= (7.3575 x 0.007/2) x ((0.008+3.14 x 0.19x0.007) / (3.14x0.007-0.19x0.008))

(T_{Ru}) = 0.01532 N-m

Speed of the motor (N) = 100rpm

Power required while upper platform ascending (Pu)

= 2 Л N T_{Ru} / 60

= 2 x 3.14 x 100 x 0.01532/60

(Pu) = 0.16 Watts

Calculation of Torque and Power while Lower Platform is Ascending

Mass of lower platform base plate, nut and support plate (m8) = 0.1Kg

Mass of lower platform magnets (m9) = 0.2Kg

Mass of lower platform springs and screws (m10) = 0.04Kg

Mass of cable (m6) = 0.125Kg

Total Mass to be lifted while lower platform is ascending

(ml) = m8+m9+m10+m6

= 0.1+0.2+0.04+0.125

= 0.465

Mean Thread Diameter (dm) = 7mm

= 0.007m

Lead (L) = 8mm

= 0.008m

Gravity (g) = 9.81 m/s^2

Load to be lifted while lower platform ascending (Fl) = m_l x g

= 0.465 x 9.81 = 4.561N

Coefficient of Friction based on table 5.1 (μ) = 0.19

Lifting Torque while upper platform is ascending (T_{Rl})

= (F_l x dm/2) x ((L+Л x μ x dm)/(Л x dm - μ x L)

= (4.561 x 0.007/2) x ((0.008+3.14 x 0.19x0.007) / (3.14x0.007-0.19x0.008))

T_{Rl}) = 0.0095 N-m

Speed of the motor (N) = 100rpm

Power required while lower platform ascending (P_l) = 2 Л N T_{Ru} / 60

= 2 x 3.14 x 100 x 0.0095/60 **(P_l) = 0.09945 Watts**

Power Required by each magnet Pm = 12Watts

Total Power required while upper platform ascending (P_{tu})

= 4 x Pm + Pu

= 4 x 12 + 0.16

= 48.16 Watts

Total Power required while lower platform ascending (P_{tl})

= 4 x Pm + P_l = 4 x 12 + 0.09945

= 48.0995Watts

RESULTS AND DISCUSSIONS

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Individual Parts Modelling of Linear Magnetic Climber is performed using CATIA V5 Software as shown in Fig (6.1)

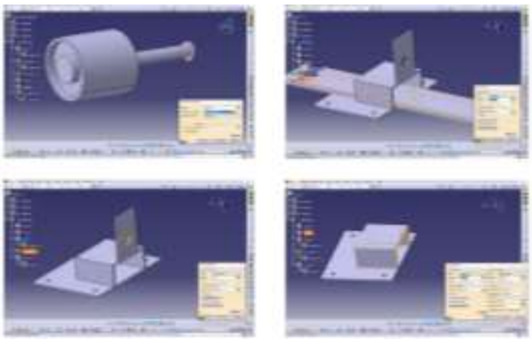

Fig (6.1) Parts Modelling of Linear Magnetic Climber

At most care is taken while modelling the parts, so that the length and width of the linear magnetic climber upper and lower platforms can accommodate magnets, lead screw, springs, telescoping channel and camera, at the same time mass of the machine does not exceed 1.5 kg

We have used 4 magnets of 27N individual capacity on each platform i.e., total 8 number of electromagnets are used on climber

Reason behind giving 4 magnets on each platform is to keep the machine stable (avoid tilting of machine during vertical travel) and to bear machine load along with electrical wiring load while climbing

70 x 100 mm plates are used for platforms considering 2 x 20mm magnet diameter and 40mm telescoping channel width. 1.5mm plate thickness is chosen as it adds very little mass on the machine without compromising weld strength

Springs are given for quick release of electromagnets from surface as soon as power is withdrawn to the electromagnets. This will avoid rubbing of magnets with metallic surface

10” telescoping channel is selected as our stroke length ranges between 4” to 6” and 10” channel will be stable / zero deflection up to 6” telescoping

Assembly of linear magnetic climber is performed using CATIA V5 Software as shown in Fig (6.2)

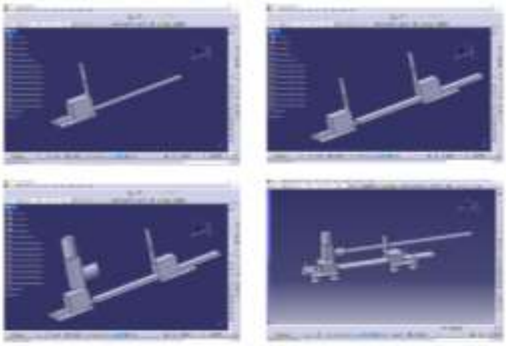

Fig (6.2) Assembly of Linear Magnetic Climber

Linear Magnetic Climber is fabricated and assembled as per modelling and wiring is done to meet the requirements of the project

Fig (6.3) Fabrication and Assembly of Linear Magnetic Climber

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We have considered Mild steel material for fabrication of components as it is cheaper, easy to source, easy to machine. Though mild steels' density is higher than aluminium it avoids several fittings (screws, nuts , bolts and ljoints) by which we can keep our mass in limits

Present machine is given with 2000mm wiring as we have considered maximum test climbing is 2000mm. However, we can increase wiring length as per requirement. Based on length of wire we can use higher capacity magnets to take additional wire mass

As per Calculations Total Power required while upper platform ascending (P_{tu}) is 48.16 Watts and Total Power required while lower platform ascending (P_{tl}) is 48.0995Watts**,** that means maximum power required per hr is 48.16Watts and with 300 Watts capacity battery we can inspect for around 6 hrs

We have tested the linear electromagnetic climber on metal surface / section of duct and it was able to hold with metal surface using bottom 4 magnets as shown in Fig (6.4)

Fig (6.4) Contraction Condition

Once bottom platform is firm on metal surface, we have to expand the telescoping channel by using lead screw motor actuation arrangement as shown in Fig (6.5)

Fig (6.5) Climbing

While climbing on metallic surface we can perform visual inspection of the metal surface with the help of camera mounted on the climber as shown in Fig (6.6)

Fig (6.6) Metal Surface Camera Image 1

Once the top platform reaches 6” expansion of telescoping channel we have to engage the top platform electromagnets as shown in Fig (6.7) and the process continues

Fig (6.7) Expanded Condition

CONCLUSIONS

Larger ducts and chimneys are common piece of sight in most of thermal power plants, oil & gas, fertilizers and other process industries. During maintenance / overhaling these ducts / chimneys are inspected manually, which is one of the time consuming and risky process as they are really tall to climb or descend. During such inspections accidents also occurs hence the situation demands for equipment’s which they themselves can climb and send visuals to inspection professionals.

As the ducts and internals of chimneys are made-up of thick carbon steel / mild steel we can use electromagnetic climbers to climb over the surfaces of these ducts and chimneys to inspect the surfaces. Linear electromagnetic climber I have developed can easily climb and send the visuals of surfaces to professionals.

Inspection of thick and large ducts & chimneys using Linear electromagnetic climber will have fallowing advantages when compared to manual inspection

- Requires less man power to operate
- No accidents as no manual climbing or descending is involved
- Low cost of inspection
- Low Investment as it is indigenous technology
- Easy to transport as it hardly requires mobile phone against large computer set up to see the visuals

During tests it is observed that this climber is very easy to operate and can be easily adopted by inspection professionals. Visuals recorded by the linear electromagnetic climber are shown in Fig (7.1)

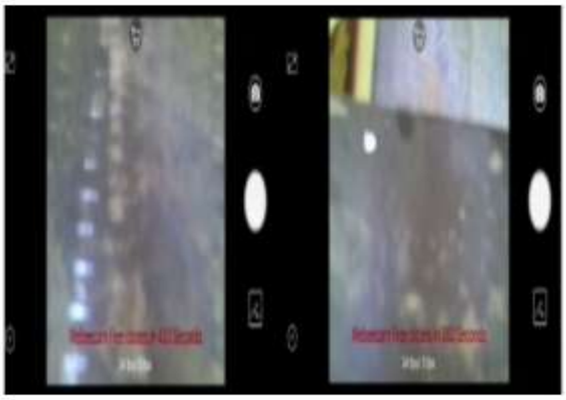

Fig (7.1) Visuals of Inspection

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Nomenclature

(Fu)	*Load to be lifted while upper platform ascending*	*N*
(μ)	*Coefficient of Friction*	
(T_{Ru})	*Lifting Torque while upper platform is ascending*	*N-m*
(N)	*Speed of the motor*	*rpm*
(Pu)	*Power required while upper platform ascending*	*Watts*
(m8)	*Mass of lower platform base plate, nut and support plate*	*Kg*
(m9)	*Mass of lower platform magnets*	*Kg*
(m10)	*Mass of lower platform springs and screws*	*Kg*
(m6)	*Mass of cable*	*Kg*
(ml)	*Total Mass to be lifted while lower platform is ascending*	*Kg*
(Fl)	*Load to be lifted while lower platform ascending*	*N*
(T_{Rl})	*Lifting Torque while upper platform is ascending*	*N-m*
(P_l)	*Power required while lower platform ascending*	*Watts*
(P_{tu})	*Total Power required while upper platform ascending*	*Watts*
(P_{tl})	*Total Power required while lower platform ascending*	*Watts*
(m1)	*Mass of motor*	*Kg*
(m2)	*Mass of upper platform base plate & motor support plate*	*Kg*
(m_m)	*Mass of each magnet*	*Kg*
(m3)	*Mass of upper platform magnets*	*Kg*
(m4)	*Mass of upper platform springs and screws*	*Kg*
(m5)	*Mass of Camera*	*Kg*
(m6)	*Mass of cable*	*Kg*
(m7)	*Mass of Threaded Rod*	*Kg*
(m_u)	*Total Mass to be lifted while upper platform is ascending*	*Kg*
(dm)	*Mean Thread Diameter*	*m*
(L)	*Lead*	*m*
(g)	*Gravity*	*m/s2*