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PNEUMATIC INSPECTION ROBOTIC DEVICES FOR RELIABLE NONDESTRUCTIVE EVALUATION OF NUCLEAR COMPONENTS

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ABSTRACT

Automation of non-destructive evaluation (NDE) methods and use of robotic devices for inspection result in significant performance enhancement in terms of efficiency cost and time. This has resulted in the development of many custom-built robotic devices, especially for applications of NDE for quality control, material characterization, in-service inspection and material assessment. The sate of art of inspection of vertical surfaces by deployment of robotic devices is highly sophisticated. The robots are to be tailor made for the specific task [2]. In this paper an attempt is made to highlight the various parameters and optimization of suction cups used for maneuvering robots on vertical surfaces.

Key works – Non-Destructive Evaluation, Inspection, Pneumatic Robot, Suction Cup

1. INTRODUCTION

In nuclear industry, top most emphasis is given to safety which is ensured among other things by high quality production and performance assessment of the components. Even though utmost care is taken during the design and production, assembly. Inspection / testing, commissioning and operation of components in nuclear plants, unforeseen degradation of the materials or critical components could occur due to the synergistic effect of stress, temperature, irradiation, environmental conditions, vibration or fretting which would have detrimental effects in the overall plant safety or availability. Hence it is essential that continuous and interim surveillance by using suitable NDE techniques be carried out to ensure the integrity and functioning of structures and components throughout the plant life. Based on the information gathered during inspection, appropriate corrective measures can be taken to keep ageing under control.

Due to the limited access and presence of hazardous environment, the deployment of robotic devices for inspection activities aids the assessment of integrity and functionality of structures and components of nuclear plants [6]. The major limitations other than the accessibility and environment, the deployment of manual assessment are reliability and repeatability of test results which is operator dependent. Robotic devices with mobility and dexterity aid in autonomous, repeatable and reliable inspection of the components in service.

The robots can be deployed to eliminate or minimize the operator dependency in Visual inspection, Ultrasonic, Radiography, Eddy current, etc. The robotic devices once installed in the region of interest, the necessary positional and inspection data can be acquired by the processing unit for the data processing and storage. These data can be retrieved for comparison with the subsequent examination with data available as a base-line data [4]. The automation of parameters increases the complexity and sophistication of the robot. The factors influencing the over all performance of the devices are the environment, parameters of consideration, mainly the design of device for manipulation of the inspection sensor and total integration of the software of the inspection module and robotic device. Various parameters in the design of the robotic device and the suction cup optimization have been discussed in this paper.

2.0 ROBOTIC DEVICES FOR INSPECTION

The robotic devices consist of, a) power source, b) a operative /manipulator mechanism c) locomotion of the system, d) control system, e) a sensor or feed back system, and f) the end effectors. The operative /manipulator system is the mechanical, electrical and pneumatic hardware for the robot. The end effectors are manipulated to achieve the desired operation by the aided of the locomotion, control system and feed back system. The end effectors shall house the Sensor, integrated sensor amplifier, which is connected to inspection module. The inspection module consists of a) signal generator and receiver, b) controller, c) display, d) data processor and e) data storage and retrieval system.

2.1 Design

The design of the robotic system is influenced by the various parameters and environment limitations shown in fig 1. The robotic device for inspection has the robot with end effectors as the inspection sensor. The robotic device has to move and maneuver on the surface of inspection. The surface of inspection determines the type and method of anchorage of the robot to the surface. The manipulation of the anchorage decides the actuators to be used in the anchorage. The mechanism of actuation and positioning the anchorage module define the configuration of the manipulator and the robotic device. The positioning accuracy of the anchorage depends on the inspection sensor. The resolution, Positional accuracy, the orientation accuracy of the inspection sensor decides the feed back mechanism, the manipulation mechanism, positioner module, and anchorage module. The modular concept in the design of the robot enhances the integration for the specific tasks depending on the environment [1].

The design parameters, for inspection and environments decide the design scheme, illustrated in Fig 2. The design scheme for inspection of the engineering surfaces can be achieved by the permutation and combinations of different modes, but optimizing the factors for inspection.

Position of the components in the robot has an importance implications on the movements and behaviors of the robot, thus optimize the design parameters of components is critical [3]. The friction is of concern in pneumatic actuator and components. For the deployment of the robot, it is deduced that a) the robot needs the modularity of the hardware and software, b) optimising the position of the component decides the design parameters of the components.

3.0 DEVELOPMENT OF A PNEUMATIC INSPECTION ROBOTIC DEVICE

The development of the pneumatic robotic device has been taken up at IGCAR, Kalpakkam, to address the need for remote inspection of vertical surfaces and inaccessible areas. The need for the pneumatic device has been conceived for the compactness. Advantages of a pneumatic system are in the energy storage, force density, transmission ratio and ease of handling. The robotic inspection device shall manipulate the sensors used in non-destructive evaluation for assessment and integrity of engineering structures.

The inspection of engineering surfaces like storage vaults, ducts, etc, requires the device to move and maneuver on the surface, and defy the action of gravity in vertical and overhead surfaces [5]. The surface contact or adhering to the surface can be obtained by magnetic pads for magnetic surfaces, wheels for the horizontal surfaces, and suction cups for vertical surfaces.

However use of vacuum suction cups makes the choice independent of material of construction of wall.

The actuation for the suction cups for positioning and its orientation can be obtained by electrical, hydraulic or pneumatic actuators. Decision for the selection of the actuator depends on the environment. The corrosive and radiation environment need to be considered in the use of electrical/ electrical components, and demand the uses of protected components are to be used like shielded or radiation resistant components. The maintenance and replacement cost are the limitation for the extensive use, thus it has to be minimised. The hydraulic has the limitation due to the cumbersome circuitry of the hydraulic feeder lines and actuators. The other alternative is pneumatic actuation, which can be extensively used in any environment; due to the compactness of the components, their maintenance and replacement are comparatively economic.

The robotic deceive is to be anchored to the surface, during the operations. Thus the safety of the robotic device is the most important consideration, as the device should be secured firmly on the surface while climbing. The two dangerous circumstances that can arise are the slipping of the robot and the falling of the robot selection. Thus the analysis of the suction cups is considered to be very critical to ensure the safety of the device during operation.

3.1 Design analysis of the suction cup

The pay load, surface, dimension, stroke, materials of construction, vacuum porting and connection being the parameters of suction cup, the parametric analysis on the diameter of the suction cup is considered to be predominant of all parameters. The analysis is based on the parametric aspects of the suction cup.

Notations

a	Acceleration of the system
m	Mass of pay load, (kg)
n	Number of Suction cups,
S	Safety Factor
μ	Coefficient of Friction
M, M_N	Moment on the suction, normal moment.
F_N, F_H, F_R, F_{th}	Normal Force in X direction , Shear Force in Y direction, Resultant force, theoretical force
R, A	Radius, effective Area of the suction cup
V, V_F, V_S, V_M	Vacuum pressure, Failure Vacuum, slipping vacuum, min require vacuum
P	Working pressure
F_T, F_B, F_θ, F_s	The force distribution on suction during anchorage at top, bottom and angular, the suction force at suction cup

It is assumed that no elastic deformation takes place. The suction cup is a rigid body and the force distribution between the suction cup and the contact surface is linear.

The suction force of the suction cups depending on the positioned to the vertical surface, considering the pay load, number of suction cups used friction at the surface of contact and the acceleration of mass against gravity. The Fig 3 shows the schematic diagram of force distribution on suction cup.

$$F_s = \{(m/\mu)*(g+a)*S\}/ n$$

The normal and shear forces acting on the suction cup,

$$F_N = \prod R^2 P$$

$$F_H = F_N * \mu$$

The theoretical radius (R) of the suction cup, considering the mass, factor of safety, number of suction cups used, and the friction at surface contact,

$$R = 0.56 \sqrt{\{(m * S) / (V_M * n * \mu)\}}$$

The normal reaction of the force distribution at the suction cup

$$F_R = \prod R (F_T + F_B)$$

The balancing the forces acting on the suction cup

$$F_R + F_N - F_s = 0$$

We have working pressure,

$$P = v - F_H / \prod R_2$$

Considering the moment (M) about the center of suction cup,

$$M_N = - \prod R^2 (F_T - F_B)$$

As $M + M_N = 0$

We obtain F_T,$= 0.5(RP – (M/\prod R^2)$

F_B ,$= 0.5(RP + (M/\prod R^2)$

To avoid the suction cup from falling $F_B > 0$

$$V_F \geq ((M/R) + F_s) / \prod R^2$$

The critical vacuum pressure for falling is

$$V_F = ((M/R) + F_s) / \prod R^2$$

The slippage of the suction cup can be avoided when friction force equals the shear Force at the suction cup, the critical vacuum for slippage

$$V_S = \{(F_H/\mu) – F_N\} / \prod R^2$$

Thus minimum vacuum pressure $V_M = \max [V_S, V_F]$

4.0 RESULTS AND INFERENCE

4.1. Influence of the Mass

The influence of pay load mass on the suction diameter and the suction force is shown in the Fig 4. The correlation of the mass of the pay load , to diameter and the suction force, with

other parameter kept constant, have limited the pay load to 20 kgs, which optimizes the suction cup diameter and the corresponding suction force. The results obtain are in validation with the author *Prof Dr. Ewald von Puttkamer, "Climbing Robot environment"[7]*

- The design of a climbing robot is determined to a larger extent by its operating environment.
- The author suggests that the weight of the robot to limited to 20kg (pay load).
- The structure strength also limits the pay load of the robot.

4.2. Influence of the Factor of Safety

The influences of the factor of safety on the diameter of the suction pads wrt the suction forces are found to proportional, as shown in the fig 5.

- The diameter set to the values of forces on horizontal and vertical combined, ie the resultant forces, shall be the design criteria.

4.3. Influence of the frictional

- From the optimization of the diameter of the suction cup and the suction forces, with respect to the frictional forces between the suction cups and surface of adhesion, we can opt for the working range, referring the Fig 6.
- Friction – 0.5 to 0.6
- Diameter of the suction cups – 80 to 90
- Suction forces – 250 – 325

4.4. Influence of friction and eccentricity

The influence of the friction and eccentricity of the suction cup spacing is a limiting factor for size of the robot, pictorially illustrated in Fig 7. The eccentricity has a proportional influence on the spacing of the suction cup, and the eccentricity of the pay load.

5.0. INFERENCES

The optimization of the parameters by the above analysis of the robot pay load is to be limited to 20 kg, which includes the end effectors, sensors with integrated amplifier module. The effective diameter of the suction cups is optimized to 80 – 90 mm. the effective area shall be considered when the suction cups are not circular. The suction cup shall be optimized by the suction force with in the range of 250 to 350 N. The eccentricity of the robot on a vertical surface is to be minimised with in the range of 75 to 100 mm, in order to reduce the chance of suction cup slipping from the point of anchorage.

6.0. CONCLUSION

The problem has been identified as the optimization of the design parameters, of the pneumatic robot. The important criteria of the pneumatic robot are anchorage module and locomotion. The component of interest in anchorage module being suction cup, its design has been taken for analysis. The working range of the parameters of suction cup has been ascertained from the results obtained from the analysis. The analysis of the suction cup was done to determine the size of the suction cup and safety of the robot by determining the minimum vacuum in the suction cups, at which the robot will detach from the contact surface. The parametric analysis for the kinematics and dynamics of the robotic device has been done.

7.0 Acknowledgements

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FIGURES

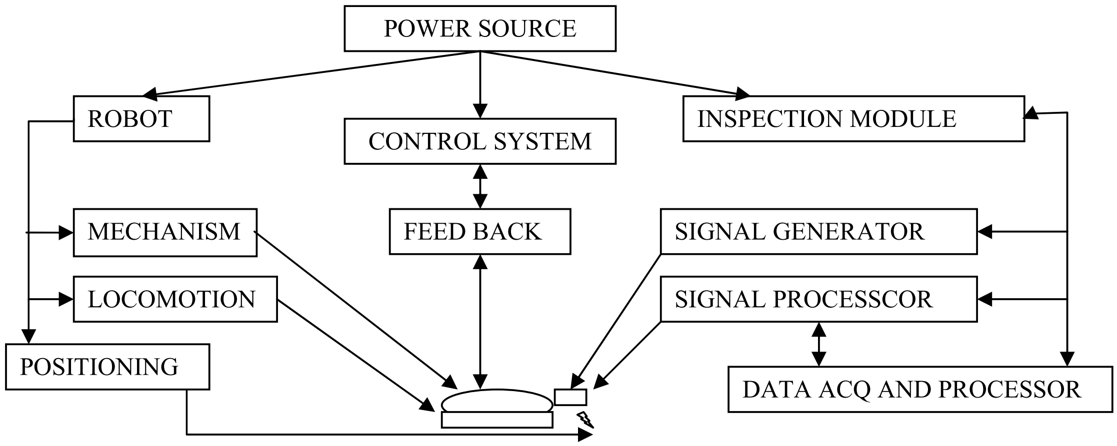


Fig 1 Schematic layout of the robot and the inspection module

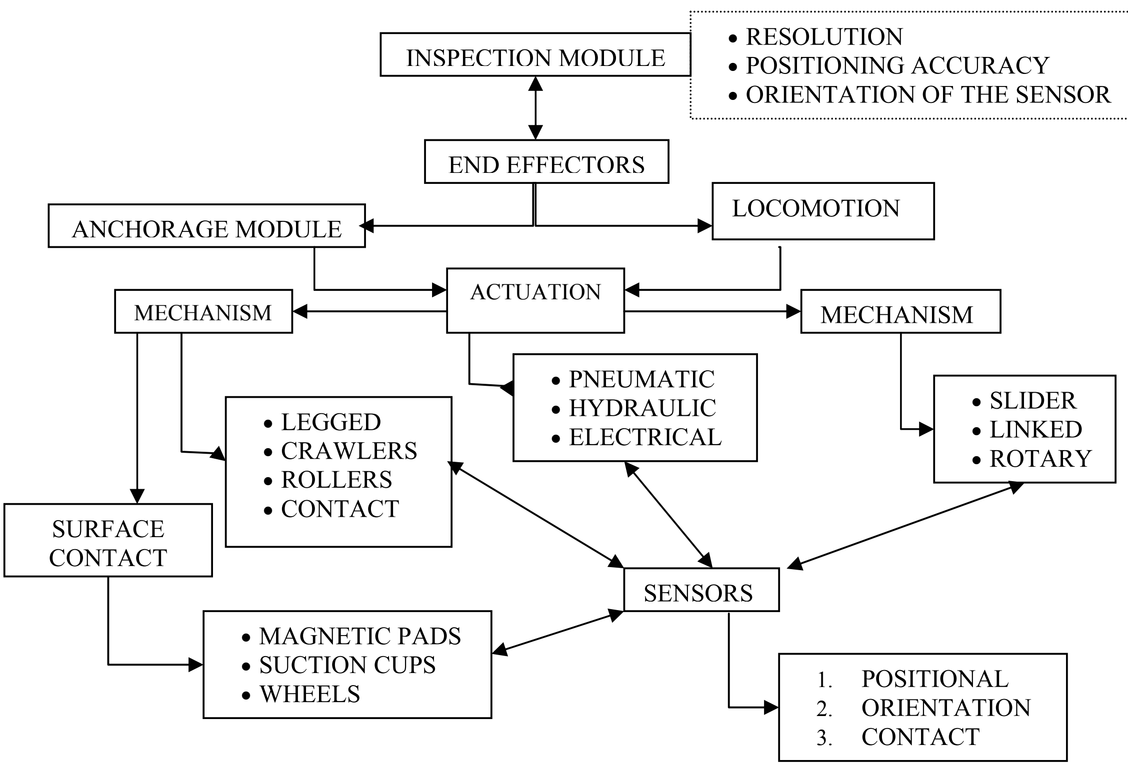


FIG 2 DESIGN PARAMETERS AND INTERDEPENDENCE SCHEME

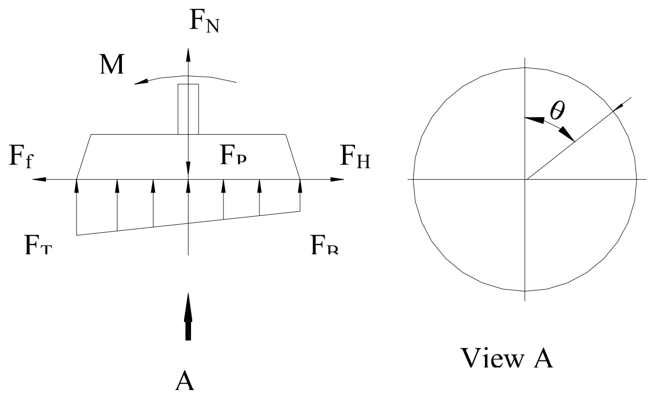
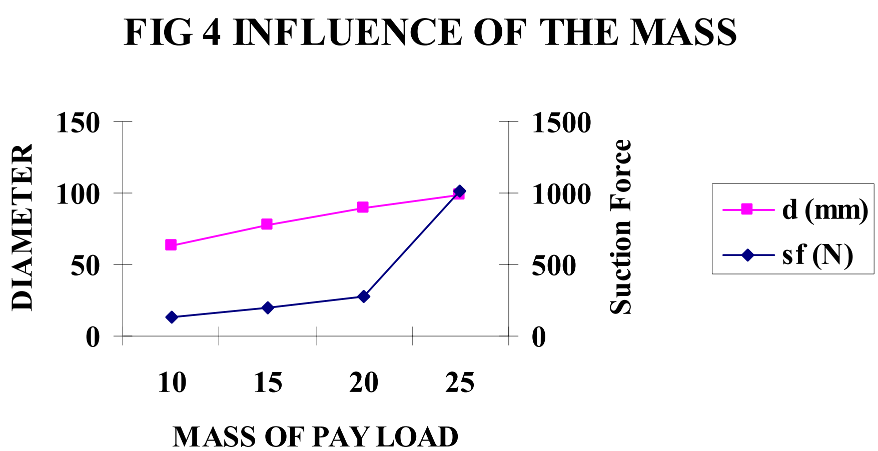


Fig 3 The schematic diagram of the suction with force distribution



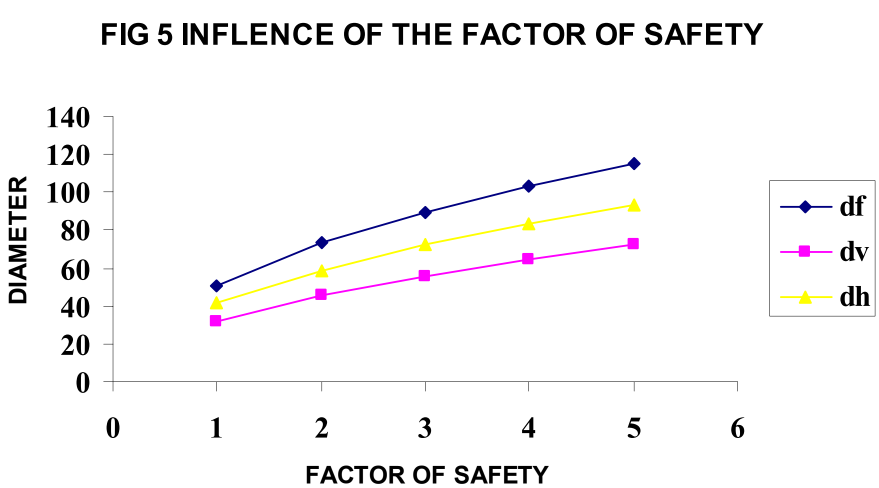
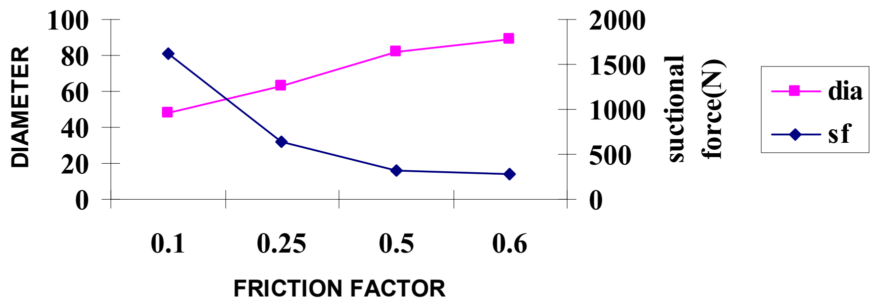


FIG 6 INFLUENCE OF FRICTION ON SUCTION CUP



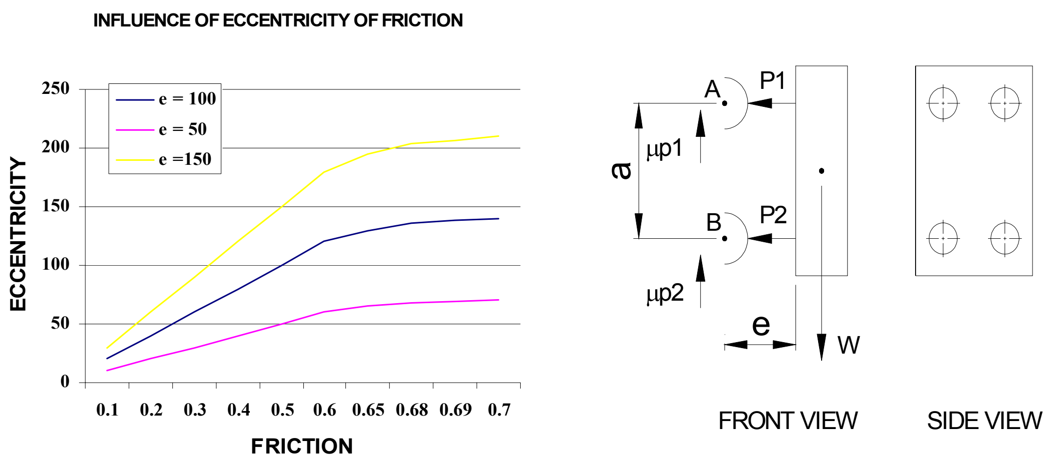


Fig 7 Influence of friction and eccentricity on suction cup spacing