Gripper Considerations for In-Vessel Tile Handling Tasks in a Fusion Reactor Vessel

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Abstract-This paper presents design issues of parallel-jaw gripper mechanism for maintenance of first wall armor protection tiles of fusion reactor vessel in tile-screwing tasks. The mechanism of wrist provides compactness and high torque capacity in gripping. The wrist has pitch and roll as two degrees of freedom. The holding task is guided by using a bell-crank lever-slider mechanism operated with a low-torque rating motor providing sliding motion to fingers. The gripper is considered as a class of unknown nonlinear discrete-time system. The gripper mechanism is implemented for unscrewing a square headed screw on the wall-tiles of a fusion reactor vessel. Various stages of this handling task are explained in detail with theoretical modeling.

Index Terms- Parallel-jaw gripper, force analysis, tile screwing, adaptive nature,

1. INTRODUCTION

Depleting fossil fuels brings to the use of fusion and fission concepts in modern world. Fusion reaction produces very high energy neutrons of order 14 MeV inside the International Thermonuclear Experimental Reactor (ITER) vacuum vessel, covered by blanket modules. This result in the first wall and port plug components (blanket modules) to be highly constrained. Many parts in the first wall region need replacements frequently. As the fusion reaction uses hazardous nuclear substance tritium, direct human intervention in the inspection tasks is not allowed. Remote handling with man in the loop at every moment is the basic technology [1-4] followed during the entire operation of the fusion reactor. For successful remote handling task, it requires (i) simplified design of components (ii) simple procedure for component replacements and (iii) simple and efficient remote handling equipment or tools. Joint European Torus (JET) is one of the Tokomak vessels, where the first successful remote handling techniques were introduced. Articulated manipulator boom with end-effector mascot serves as a remote handling device for in-vessel inspections. The remote handling (RH) equipment enters through the access port into the torus vacuum vessel. RH equipment performs the following functions: (a) in-vessel maintenance (b) in-vessel viewing (c) in-cryostat maintenance (d) hot cell repair and (e) RH test stand operations. For in-vessel maintenance, the RH equipment maintains components like: diverters, first-wall blanks, cryopumps, test blanket modules, feed-pipes and post resident components,

Recently several works reported the use of RH robots in vacuum vessels. Pagala *et al*. [5] illustrated the use of modular robot system for maintenance and inspection tasks inside the hot cell. Maruyama *et al.* [6] employed a vision-based robotic system for remote handling task in the blanket module of ITER with two cameras.

In this line, the robotic device should have a specific grasping mechanism for wall tile replacements as well as for cleaning of transparent surfaces on the blanket. Generally, a specific grasping tool is often used, which adapts to the task and manipulation objects [7-9]. Its ability to change grasps in response to changes in the tasks is an interesting issue. Even several multi-fingered robotic hands developed in laboratories; still the conventional 3-DOF wrist with two finger motions is quite commonly seen in many applications. In parallel-jaw gripper, the finger-tip surfaces used to contact the part remain parallel as the tool opens and closes. Several designs are available including parallel bar and rack-and-pinion mechanisms for activating the gripper. A good summary about their operation was provided by Choi and Koc [10].

Present paper attempts the design and analysis of two-jaw parallel gripper for holding operations of tile screws. The overall manipulator arm has total 7 degrees of freedom with wrist providing roll and pitch motions. A boom may be arranged at the wrist so as to adjust the height and distance above the tile surface. The remaining part of the paper is arranged as follows: section-2 deals with the description of the problem and necessity of gripper mechanisms. Section-3 presents some of the outputs of the force analysis. Brief conclusions are given in section-4.

2. DESCRIPTION

There are multiple issues involved in the design of the wrist and gripper linkage. It should be remotely operated, it should enter the vessel through available port sizes, there should be vision camera attached at the wrist for monitoring, motors should be operated with man-in-loop configuration and finally, the end-effector (after wrist) should able to twist the tile screws in case of the replacement requirements.

2.1. *Armor tiles Monitoring and Replacement*

This is an open problem attempted over the last two decades by several researchers. The manipulator from wrist zone is allowed to pass into the vessel and should be large enough to approach the cylindrical wall surface. Monitoring the surface of first wall using a high speed CCD vision camera mounted at the wrist joint is straight forward issue. However, once the any abnormal wall surface is found, the immediate task is to replace the tile with a new one. The wall tiles are flexibly connected to the surface using screws/bolts. The high temperature plasma during working hours may induce thermal as well as mechanical stresses on these tiles and bolts, leading to loosening and tile cracks. Fig.1 shows one of the ideal views of the gripper required to handle the tile bolts so as to remove the tile.

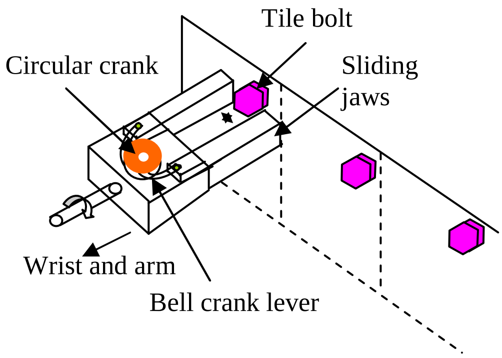

Fig.1 A rough schematic of bolt handling

After the tile bolt is taken out, the tile falls into a waste-tile carrier bin and replacement of tile is postponed till the entire inspection is completed. For replacement with new tile, the present wrist design has to be modified such that it should first keep the new tile on the wall surface and hold it and later another arm should come with a tile bolt to tighten in the hole. Alternatively, a carrier containing the new tiles and bolts has to come from other side and entire process is done automatically, which is an existing procedure in the ITER vessel operation task [11,12].

2.2. *Design of linkage*

The mechanism has 5 degrees of freedom arm with wrist having 2 additional degrees: pitch and roll. A sliding motion at the wrist can also be provided in the design. The end-effector (gripper) is a parallel jaw type. Two designs are considered: in first design conventional geared 4-bar linkages with worm transmission is used as shown in Fig.2.

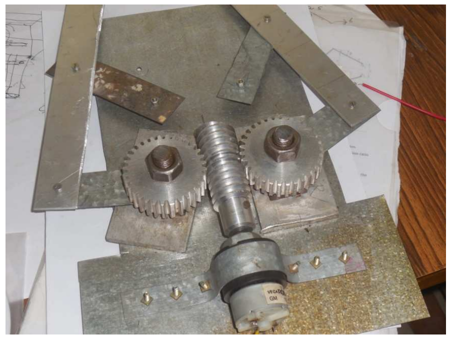

Fig.2 Standard design of worm-wheel gripper

Here the transmission ratio is high, however, it is difficult to hold the bolt firmly. Fig.3 shows the linkage configuration.

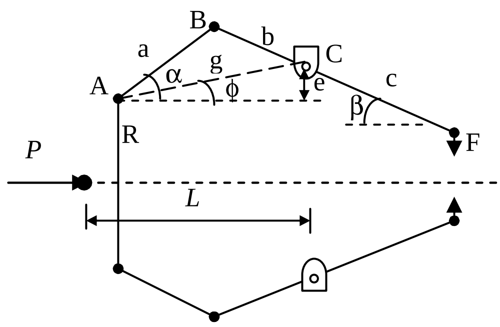

Fig.3 Schematic of gripper

The gripping force F can be expressed in terms of the force P applied by taking moments about pivot C as follows:

$$F = \frac{bP\sin(\alpha+\beta)}{2c\cos\alpha\cos\beta} \qquad (1)$$

Where

$$\alpha = \cos^{-1}\left(\frac{a^2+g^2-b^2}{2ag}\right)+\phi \qquad (2)$$

$$\beta = \cos^{-1}\left(\frac{b^2+g^2-a^2}{2bg}\right)-\phi \qquad (3)$$

$$g^2 = (L-e)^2+e^2 \qquad (4)$$

Using this it can be seen that the gripping force variation as a function of the angle ϕ is nonlinear. In another design based on the compliant model supplied by Robokits Company, a lever connected crank operated with vertical motor is employed. The other ends of lever are connected to the two jaws of gripper as shown in Fig.4. This design is some what robust in the sense that it can apply the force at a single Xlocation. It does not require any gear pair or other complexities. Also the design is compact.

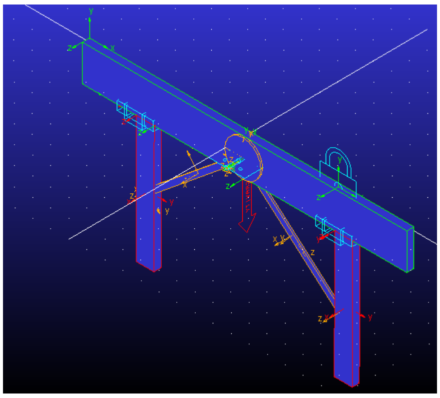

Fig.4 The model of compliant gripper

3. BRIEF RESULTS

Model results are illustrated for a small case. Table-1 shows the input data taken for the gripper.

Table 1. Dimensions of gripper

Parameter	Value
a	20mm
b	20 mm
c	30 mm
L	40 mm
e	15 mm
R	30 mm

Fig. 5 shows the variation of gripping force ratio as a function of angle ϕ. It is exponentially increasing trend.

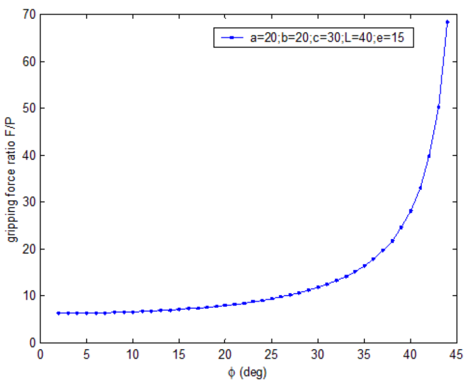

Fig.5 Gripping force ratio for case-1 mechanism

For the case-2 model, the kinematic simulations and the dynamic analysis is carried using ADAMS2013 software. The work is under progress.

4. CONCLUSIONS

Some of the considerations for gripper in handling wall tile screws/bolts have been briefed-out in this paper. The gripper should able to provide enough twisting moment to unscrew or screw the bolts. Two simple two-jaw gripper designs are given. The effectiveness of the gripper is still under study.

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