International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 3.45 (SJIF-2015), e-ISSN: 2455-2585
Volume 3, Issue 12, December-2017

TOLERANCE SYNTHESIS OF 3R PARALLEL ROBOT MANIPULATOR

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Abstract*— This paper focus on the tolerance synthesis of a parallel robot manipulator with 3Revolute joints. The present work deals with making the dimensions of the robot manipulator robust and compute the optimal dimensional tolerances for a given 3R parallel robot manipulator for minimising the positioning error of end effector of robot with given target.For making the dimensions robust a proper robustness index has to be chosen.Obtained robust dimensions must tolerate globally to largest variations. Then to compute the optimal dimensional tolerances from the given robust dimensions a new tolerance synthesis method developed by Stephane Caro is used .This method is known as Caro-Tolerance box method. the optimal dimensional tolerances are calculated by optimal dimensional algorithm.The values of robustness index and optimal dimensional tolerances are validated.

***Keywords*— robust design, tolerances, optimal, variations, sensitivity, robustness index, tolerance synthesis, 3R parallelmanipulator**

1. INTRODUCTION

Parallel manipulators possess significant advantages over serial manipulator in terms of dynamic properties, load-carrying capacity, high accuracy as well as stiffness. This is because parallel manipulators are characterized by several kinematic chains connecting the base to the end-effectors, which allows the actuators to be located on or near the base of the manipulator. Therefore, parallel manipulator can be used in many applications where these properties are of primary importance while a limited workspace is acceptable.

Gough built the first hexapod to test tires. This parallel manipulator is commonly referred to as “Gough-Stewart platform” and now generally accepted in the robotics and manipulators community. But the most common application of parallel manipulators is in flight simulation, as originally proposed by Stewart. Although flight simulators have been used for several years, Hunt introduced the concept of parallel manipulator and suggested, using this type of manipulator in robotics. Since then, parallel manipulators have been given considerable attention. The number of applications in which parallel manipulators are used has been steadily increasing and several prototype manipulators have been built. For instance, parallel manipulators can also be used as machine tools or even for medical purpose. So far, many types of parallel manipulators have been proposed. Other applications of parallel manipulators are adjustable articulated trusses, walking machines and high-speed, high-precision, multi d.o.f machining centre.

There are some factors limiting the application of parallel manipulators. One main factor is that the workspace of parallel manipulators is quite limited, because the closed-loop nature of parallel manipulators limits the motion of the platform. The other one is that singular configuration, the number of degrees of freedom of the manipulator changes instantaneously. If the manipulator gains one or more degrees of freedom, it becomes uncontrollable. Furthermore, in such a singular configuration, the actuator forces can become very large, which may result in a breakdown of the manipulator.

Most of the 6-dof parallel manipulators studied to date consist of six extensible limbs. These parallel manipulators possess the advantages of high stiffness, low inertia, and large payload capacity

2. Robust Design problem for 3R Robot Manipulator

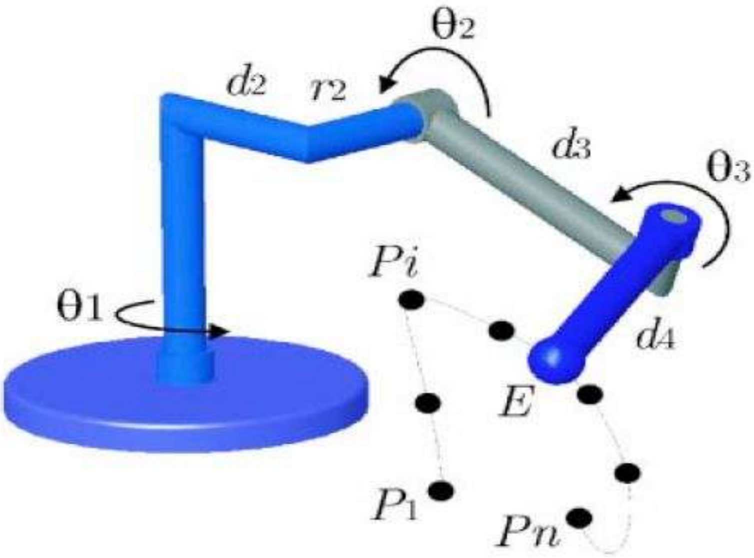

FIG 13 R robot manipulator

according to [7] In every robust design problem, the difference is made between three sets: (i) the set of design variables (*DV*); (ii) the set of design parameters (*DP*); (iii) the set of performance functions. in the present work of 2R serial robot manipulator mechanism design variables are link lengths and design variables are force acting on the manipulator and coefficient of friction between the link lengths. The *l*-dimensional vector of design variables is denoted by $\mathbf{x} = [x_1 x_2 \cdots x_l]^T$. The *m*-dimensional vector of design parameters is denoted by $\mathbf{p} = [p_1 p_2 \cdots p_m]^T$. Performance functions are grouped into the *n*-dimensional vector $\mathbf{f} = [f_1, f_2 \cdots f_n]^T$.*Design Variables* are subjected to uncontrollable variations because of manufacturing errors, wear, or other uncertainties, .According to [] A mechanism is robust when the sensitivity *S* of its performances to variations is a minimum. Therefore, *S* can bedefined as the ratio of the Euclidean norm of variations in its performances, $\|\delta f\|_2$, and the Euclidean norm of variations in *DV* and *DP*, $\|\delta X\|_2$.

f = **f**(**x**,**p**) (2.1)

$$\delta f = [Jx\ Jp][\delta x^T\ \delta p^T]^T = J\ dX \quad (2.2)$$

According to [7]*S* represents a variation transmission ratio and means the amount of variations transmitted from the sources to the design. Besides, eq.(2.3) follows from eq.(2.2) and means that *S* is bounded by the smallest singular value, $\sigma_{\min}$, and the largest singular value, $\sigma_{\max}$, of sensitivity Jacobian matrix **J**.

$$\sigma_{\min} \le S = \frac{\|\delta f\|_2}{\|\delta f\|_2} \le \sigma_{\max} \quad (2.3)$$

3. Robustness Indices

In order to obtain a robust solution independently of the amount of variations in *DV* and *DP*, a judicious robustness index is required. The robustness indices usually found in the recent literature are the condition number and the Euclidean norm of the sensitivity Jacobian matrix, **J**. Al-Widyan and Angeles [7], Ting and Long [8] used the condition number of **J**. Zhu [9] and Hu et al. [10] suggested the use of the Euclidean norm of **J**. In this section, it is shown that the Euclidean norm of **J** is more appropriate for the robust design of mechanisms. The condition number of a matrix is the ratio of its largest singular value to its smallest singular value. Let RI_1 be the condition number of **J**.

$$RI_1 = \|J\|_2 \|J^{-1}\|_2 = \frac{\sigma_{\min}}{\sigma_{\max}} \quad (3.1)$$

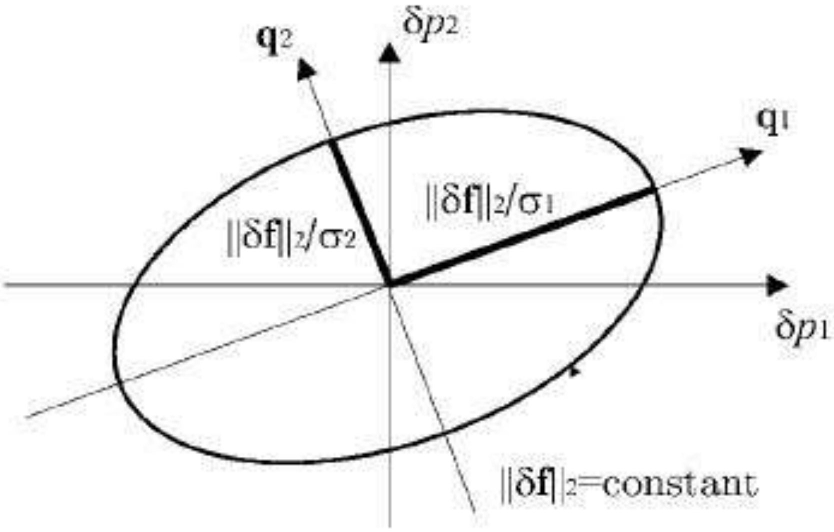

Fig 2. Design sensitivity ellipsoid

As there are several robust manipulators, the designer canchoose another criterion to be optimized. For instance, he cantake into account the cost or the complexity of the mechanism.Here, the optimal robust manipulator is supposed to be the onewith the best dexterity. This criterion is frequently used in manipulatordesign. It evaluates the ease of a manipulator to executemotions or arbitrary motions in all directions. It is quantified bythe condition number of its kinematic Jacobian matrix. Thesmaller the condition number, the higher the dexterity. Besides,themanipulator is isotropic when its condition number is equal to one. Let $\mathbf{J}_k$be the kinematic Jacobian matrix of the 2*R*manipulator:

$$\mathbf{J_k} = \begin{pmatrix} C_1 & -S_1 & C_2C_1 \\ S_1 & C_1 & C_2S_1 \\ 0 & 0 & S_2 \end{pmatrix} \quad (3.2)$$

$$S_1 = \sin\theta_1$$

$$S_2 = \sin\theta_2$$

$$C_1 = \cos\theta_1$$

$$C_2 = \cos\theta_2$$

5. CARO-TB tolerance synthesis method

[1]Some works in the literature deal with the link between dimensional tolerances and product cost Here, the cost of a mechanism is supposed to decrease when its dimensional tolerances increase. Thus, a new tolerance synthesis method is proposed, which aims at finding the largest tolerance box of a mechanism that does not include rejects. Let j (*C*) be the design sensitivity ellipsoid of a mechanism corresponding to a norm of variations in its performance equal to *C*. Assuming that this norm has to be smaller than *C*, the optimal tolerance box is supposed tobe the largest box included in j (*C*). This tolerance box called Caro-TB[1] it is smaller than Zhu-TB, but does not include any reject. The choice of the tolerance box depends on the wish of the designer. However, it is always important to know the solution without rejects because the cost of the loss due to rejects can be estimated from this solution.First, nominal values $x=[x_1x_2.......x_l]^T$of design variables are computed from robustness index RI_2 presented in Section 3.Then, their optimal dimensional tolerances Δx_{iopt} are computed using the following optimization algorithm.

6. Design Optimization Algorithm

$$\{ \max| b_1b_2b_3|$$

$$\text{s.t. } U(b_1, b_2, ...b_i) \in \xi_{mr}$$

$$b_1 \geq 0$$
$$b_3 \geq 0$$
$$|b_i| \geq \Delta x_{i\,min}\,,\ \text{i=1,…..3.}\}|$$

where$\Delta x_{1\,min} = 1\mu m,\ \Delta x_{2\,min} = \frac{r_2}{d_2}\Delta x_{1\,min}\ ,\Delta x_{3min} = \frac{d_3}{d_2}\Delta x_{1\,min}$

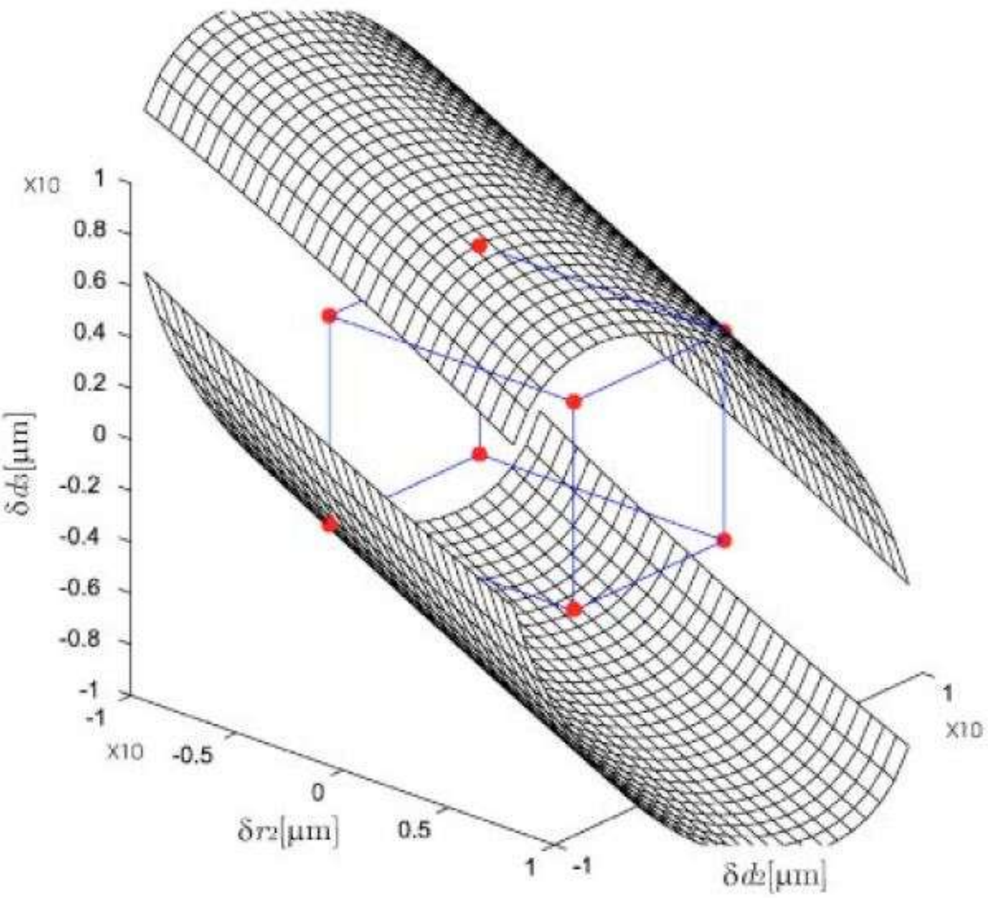

Fig .2The most restrictive ellipsoid and the optimal tolerance box

7. Results and Discussions

The results of this optimization problem are:

$$b_1 = 4.07\mu m b_2 = -5.67\mu m b_3 = 4.07\mu m$$

Figure 16 depicts the values of *E* when Thus,$\delta d_2, \delta r_2, \delta d_3$are between $-\Delta d_{2opt}$ and Δd_{2opt}, $-\Delta r_{2opt}$ and Δr_{2opt}, $-\Delta d_{3opt}$ *and* Δd_{3opt}respectively, and for the five poses of the manipulator. *E*is always smaller than 10 mm. It means that the positioning error of *E* is smaller than 10 mm for any posture of the manipulator when the tolerances of d_2,r_2, and d_3 *are* Δd_2 ,Δd_3, Δr_2, respectively. Points B_1(1,0,0), B_2(-1,0,0), B_3(0,-1,0), B_4(0,1,0),B_5(0,0,1), and B_6(0,0,-1) belong to all design sensitivity ellipsoids of the manipulator because a unitary variation of a design variable and no variation of the others lead to a unitary variationof the position of E. As an ellipsoid is a convex volume, octahedronB1 , B2 , B3 , B4 , B5 , B6 depicted in Fig. 17 is included inall the design sensitivity ellipsoids of the manipulator such that a point on the surface leads to a positioning error of E equal to 10mm. It follows that Eq. 16 is a sufficient condition for the positioning error of E to be smaller than 10 mm whatever its pose:

$$\Delta d_2 + \Delta r_2 + \Delta d_3 \leq 10\mu m \qquad 7.1$$

Without the tolerance synthesis method proposed, the designer would have chosen dimensional tolerances by means of $\Delta d_{2,}\ \Delta d_{3,}\Delta r_2$ does not respect Here, Δd_{2opt} ,Δd_{3opt} ,Δr_{2opt}, do not

Respect 7.1because$\Delta d_2 + \Delta r_2 + \Delta d_3$ =13.81mm. Itmeans that the optimal tolerance box is not included in octahedronB1,B2,B3,B4,B5,B6, as depicted by Fig. 17. However, theyallow the positioning error of E to be smaller that 10 mm at each pose P_i, i=1,2,,..5. So, knowing the target of the manipulator, thetolerance synthesis method proposed is more interesting than thesufficient condition, defined by Eq. 16!, to synthesize its dimensionaltolerances.

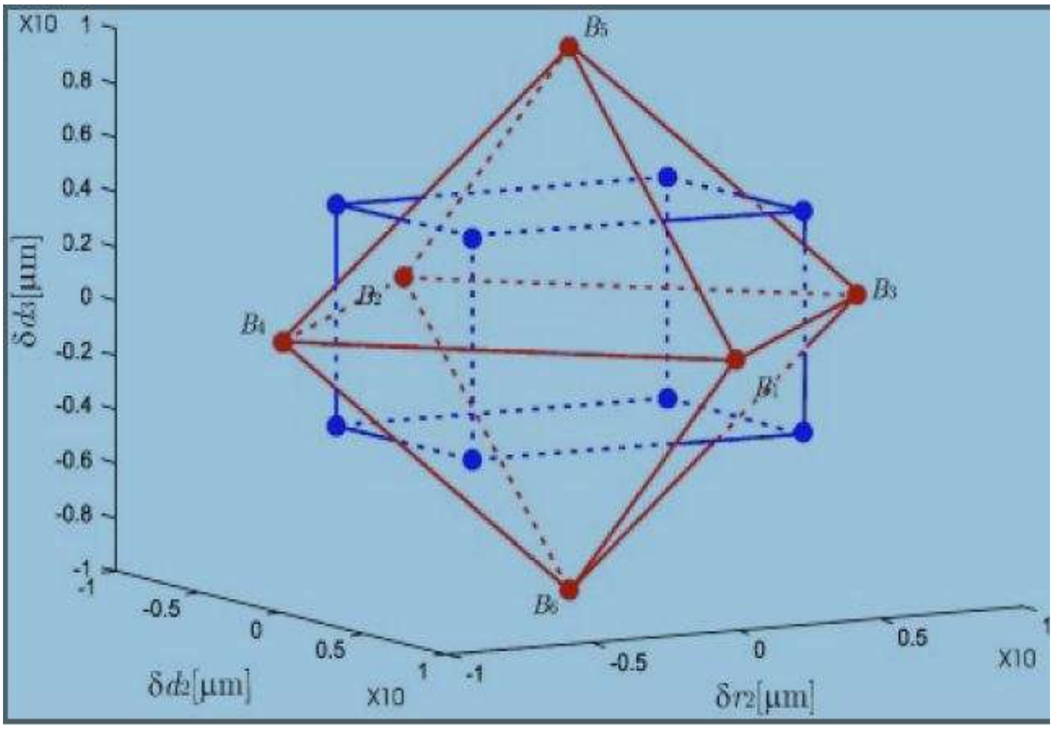

Fig 3. Caro optimal Tolerance Box[1]

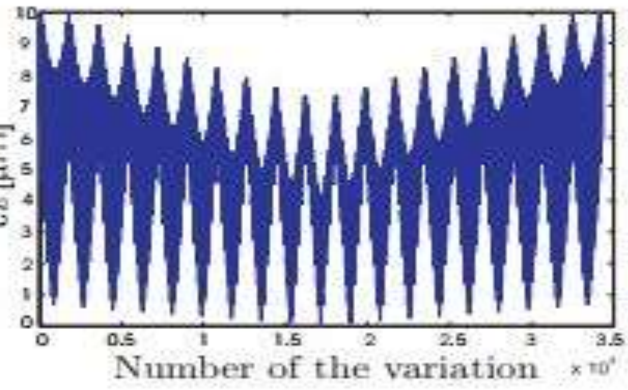

Fig4Validation of optimal tolerance box

8. Conclusions.

This paper has given an effective tolerance synthesis technique for components, in view of a powerful plan approach. The investigation of the vigor of a system takes after two back to back advances, which are free and reciprocal. The initial step goes forprocessing its strong measurements by methods for a suitable heartiness record. The Euclidean norm of the sensitivity Jacobianframework is such a list. The investigation of a damper affirmed that the Euclidean norm of its sensitivity Jacobian lattice is more appropriate than its condition number, to measure the heartiness of an instrument. This technique yields the arrangement of all the hearty manipulators and enables the architect to incorporate other criteria. At that point, the created tolerance synthesis strategy is utilized to register the ideal tolerance box of the chose hearty controller. The hypothesis is shown by two serial manipulators. The utilization of this hypothesis to the hearty plan and tolerance synthesis of parallel manipulators is one of the following stages in our examination work**.**

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