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Constraint analysis of 3-D kinematic clamps using screw algebra

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Abstract

A kinematic clamp uses three-vee or tetrahedron-vee-flat and spherical ball contacts to achieve six constraints. In this paper, we designed 3-D kinematic clamps using three pairs of vee grooves and spherical ball contact on three different orthogonal surfaces. Constraint analysis has been carried out using screw algebra. A wrench is defined along the constraint line between the contacting surfaces. Three pairs of spherical ball and vee groove are defined in different directions, and constraint analysis is performed. Prototypes for different configurations are fabricated using 3d printing. The developed methodology will be further used to design 3-D kinematic clamps for the precise positioning of components. Three pairs of spherical ball and vee groove may lie on any arbitrary surface, and any orientation and constraint analysis can be performed using screw algebra.

3D kinematic clamp, vee groove with the ball, screw theory precision, positioning

1. Introduction

In 1876, James Clerk Maxwell explained the three vee grove coupling for definite positioning. Kinematic coupling is generally used in manufacturing, fixturing and material handling for high repeatability and accuracy [1]. It is a very cost-effective and reliable method to attain the desired requirement [5]. A well-designed kinematic coupling will have the exact same no of the contact point. Generally, kinematic clamps have two configurations – a) tetrahedron-vee-flat and b) three-vee grooves and spherical ball contacts [2]. Six contacts between the sphere and flat surfaces provide six constraints, and thus the kinematic design provides an exactly constrained design [3]. The kinematic coupling thus formed is deterministic and repeatable, which reduces the cost to manufacture and predicts the performance [8].

In this paper also, kinematic clamps are designed by using three vee grooves but located on different planes and spherical balls. Therefore, they are referred to as 3-D kinematic clamps. Various arrangements of vee grooves – a) Vee grooves along the edges of a cube, b) Vee grooves on orthogonal planes of a cube and parallel to the axes, c) Vee grooves on the face diagonals of a cube (y-configuration), d) Vee grooves on the face diagonals of a cube (delta-configuration) [2] are studied and analysed. Screw theory is used for the constraint analysis of mechanisms [9]. Constraint lines are defined at the point of contact and are normal to the surface [8]. Wrenches of the constraint line are written[10], and constraint analysis is performed

2. Freedom and constraint of a rigid body

A rigid body has a total of six degrees of freedom (DOF) in the space, three translational and three rotational motions along its orthogonal axes. A mechanical connection or a contact between the two rigid bodies reduces the DOF and therefore applies a constraint on a rigid body. A constraint line is defined along the direction of the constraint applied [6].

In screw theory, DOF is represented by a twist and a constraint is represented by a wrench [9]. A twist $\hat{\boldsymbol{T}}$ consists of two vectors representing an angular velocity $\boldsymbol{\Omega}$ and a linear velocity $\mathbf{V}$, i.e., $\hat{\boldsymbol{T}} = (\boldsymbol{\Omega}|\mathbf{V})$. A wrench $\widehat{\boldsymbol{W}}$ consists of two vectors representing a force $\mathbf{F}$ and a couple (moment) $\mathbf{M}$ acting on a rigid body, i.e., $\widehat{W} = (\mathbf{F}|\mathbf{M})$. For a rigid body free in space, the six DOFs are represented by the principal twists as

$$\begin{aligned} \hat{T}_{Rx} &= (1\,0\,0\,|\,0\,0\,0) \\ \hat{T}_{Ry} &= (0\,1\,0\,|\,0\,0\,0) \\ \hat{T}_{Rz} &= (0\,0\,1\,|\,0\,0\,0) \\ \hat{T}_{Tx} &= (0\,0\,0\,|\,1\,0\,0) \\ \hat{T}_{Ty} &= (0\,0\,0\,|\,0\,1\,0) \\ \hat{T}_{Tz} &= (0\,0\,0\,|\,0\,0\,1) \end{aligned} \tag{1}$$

Where $\hat{T}_{Rx}$, $\hat{T}_{Ry}$, and $\hat{T}_{Rz}$ are the rotations along xyz – axes, and $\hat{T}_{Tx}$, $\hat{T}_{Ty}$, and $\hat{T}_{Tz}$ are the translations along xyz – axes, respectively.

2.1. Constraint analysis of a ball in a vee groove

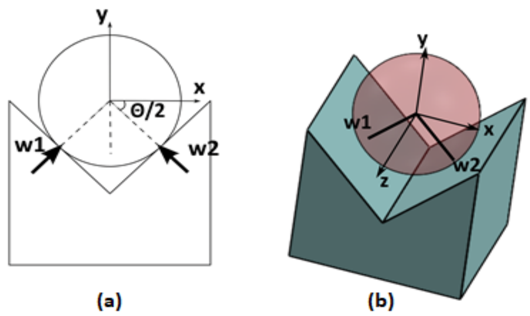

Figure 1. Ball in a vee groove: (a) Representation of constraints in *xy*-plane, (b) 3-D representation of constraints applied

If a ball is placed in a vee groove with an angle θ, it makes two-point contact with the surfaces of the vee groove, as shown in Fig. 1. It applies two constraints along with $\mathbf{w_1}$ and $\mathbf{w_2}$ and therefore reduces the two DOFs. The constraints are represented by two wrenches $\widehat{w_1}$ and $\widehat{w_2}$ along the constraint lines as follows

$$\hat{w}_1 = \left(\cos\frac{\theta}{2}\ \sin\frac{\theta}{2}\ 0 \,\middle|\, 0\ 0\ 0\right) \qquad (2)$$
$$\hat{w}_2 = \left(-\cos\frac{\theta}{2}\ \sin\frac{\theta}{2}\ 0 \,\middle|\, 0\ 0\ 0\right)$$

The general motion of a rigid body is represented by a general twist $\hat{T}$ as

$$\hat{T} = (\Omega_x\ \Omega_y\ \Omega_z |\ V_x\ V_y\ V_z) \qquad (3)$$

When a constraint is applied to a rigid body, the motion possible (instantaneous) is only along the perpendicular direction to the constraint line. Therefore, using the reciprocity condition of the screws, we can write

$$\hat{T} \circ \hat{W} = \boldsymbol{F} \cdot \boldsymbol{V} + \boldsymbol{M} \cdot \boldsymbol{\Omega} = 0 \qquad (4)$$

Applying the reciprocity condition, we get $V_x = V_y = 0$, and therefore the general twist for the given case is

$$\hat{T} = (\Omega_x\ \Omega_y\ \Omega_z |\ 0\ 0\ V_z)$$

It can be further written as four independent twists as

$$\hat{T_1} = (0\ 0\ 0\ |\ 0\ 0\ 1)$$
$$\hat{T_2} = (1\ 0\ 0\ |\ 0\ 0\ 0) \qquad (5)$$
$$\hat{T_3} = (0\ 1\ 0\ |\ 0\ 0\ 0)$$
$$\hat{T_4} = (0\ 0\ 1\ |\ 0\ 0\ 0)$$

Above constraint pattern analysis states that two translational motions are constrained, but the body is free to translate in the z-direction and rotate about all three orthogonal axes. The same can be obtained through inspection as well.

2.2. Constraint analysis of 3-D kinematic clamp

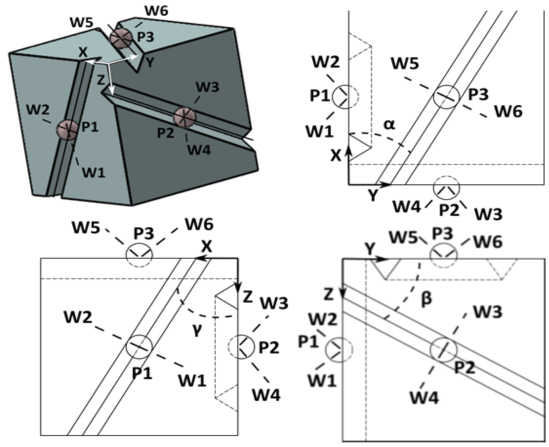

Figure 2. A physical arrangement of the body is constrained by the three pairs of spherical balls and vee groove at an angle α, β, ϒ.

In 3-D kinematic clamps, vee grooves are made on three orthogonal surfaces. Origin O of the global Cartesian coordinate system is taken as the vertex of the cube, and X, Y, Z - axes are along the edge of the cube (Fig. 2). P1, P2, P3 are the centre of the three spherical balls with respect to the Origin O. A local Cartesian coordinate system is considered at the centre of each sphere having the z-axis along the vee groove. The y-axis is coincident with the line passing through the centre of the sphere and the apex of the vee groove. α, β, ϒ is the projected angles between the z-axis and the X, Y, Z-axis on the plane XY, YZ and XZ, respectively. (Fig. 2.). Assumptions point P1, P2, P3 lie on the plane XZ, YZ, XY, respectively.

Three pairs of the ball and vee groove provide six constraints, which are represented as wrenches $\hat{W}$

$$\hat{W} = [Ad]\hat{w} \qquad (6)$$

Here, $\hat{w}$ and $\hat{W}$ are the wrenches before and after the transformation.$[Ad]$ is 6 X 6 matrix given by [11]

$$[Ad] = \begin{bmatrix} R & 0 \\ DR & R \end{bmatrix} \qquad (7)$$

Where $[R]$ is the 3x3 rotation matrix and $[D]$ is the skew-symmetric matrix defined by translational vector d= $(d_X d_Y d_Z)$

$$[R] = [X\ Y\ Z]\,,\ [D] = \begin{bmatrix} 0 & -d_Z & d_Y \\ d_Z & 0 & -d_X \\ -d_Y & d_X & 0 \end{bmatrix}$$

Wrenches for the general case are given as:

$$\hat{W}_1 = (-c\emptyset.c\gamma \quad -s\emptyset \quad c\emptyset.s\gamma\ |\ s\emptyset \quad -c\emptyset.s\gamma - c\emptyset.c\gamma \quad -s\emptyset)$$
$$\hat{W}_2 = (c\emptyset.c\gamma \quad -s\emptyset \quad -c\emptyset.s\gamma\ |\ s\emptyset \quad c\emptyset.s\gamma + c\emptyset.c\gamma \quad -s\emptyset)$$
$$\hat{W}_3 = (-s\emptyset \quad c\emptyset.s\beta \quad -c\emptyset.c\beta\ |\ -c\emptyset.c\beta - c\emptyset.s\beta \quad -s\emptyset \quad s\emptyset)$$
$$\hat{W}_4 = (-s\emptyset \quad -c\emptyset.s\beta \quad c\emptyset.c\beta\ |\ c\emptyset.c\beta + c\emptyset.s\beta \quad -s\emptyset \quad s\emptyset) \qquad (8)$$
$$\hat{W}_5 = (c\emptyset.s\alpha \quad -c\emptyset.c\alpha \quad -s\emptyset\ |\ -s\emptyset \quad s\emptyset \quad -c\emptyset.s\alpha - c\emptyset.c\alpha)$$
$$\hat{W}_6 = (-c\emptyset.s\alpha \quad c\emptyset.c\alpha \quad -s\emptyset\ |\ -s\emptyset \quad s\emptyset \quad c\emptyset.s\alpha + c\emptyset.c\alpha)$$

Here, $c\emptyset = \cos\frac{\theta}{2}$, $s\emptyset = \sin\frac{\theta}{2}$

θ is the angle of the vee groove

$c\alpha = \cos\alpha$, $s\alpha = \sin\alpha$, $c\beta = \cos\beta$, $s\beta = \sin\beta$, $c\gamma = \cos\gamma$, $s\gamma = \sin\gamma$.

The constraint space matrix is written as

$$\prod_w = [\hat{W_1}, \hat{W_2}, \hat{W_3}, \hat{W_4}, \hat{W_5}, \hat{W_6}]^T \qquad (9)$$

2.2.1 Case 1. Vee grooves along the edges of a cube

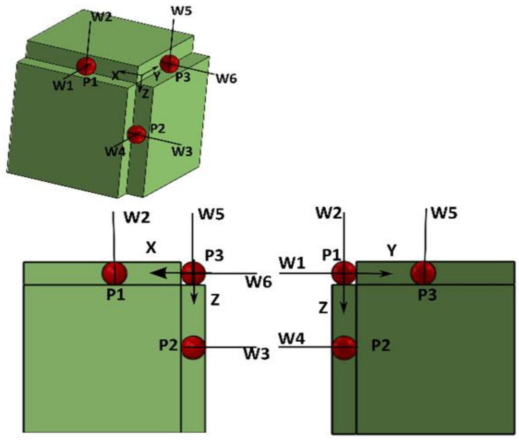

Figure 3. A physical arrangement of the body is constrained by the three pairs of spherical balls and vee groove along the edges of a cube

In this case, vee grooves are placed along the orthogonal edges of the cube that passes through Origin. i.e., the z-axis coincides with the X, Y, Z-axis, respectively. α = β = ϒ = 0° and θ = 90° as shown in Fig. 3.

Wrenches for case 1 are

$$\hat{W}_1 = (0\ \text{-}1\ 0\ |\ 0\ 0\ \text{-}1)$$
$$\hat{W}_2 = (0\ 0\ \text{-}1\ |\ 0\ 1\ 0)$$
$$\hat{W}_3 = (\text{-}1\ 0\ 0\ |\ 0\ \text{-}1\ 0) \qquad (10)$$
$$\hat{W}_4 = (0\ \text{-}1\ 0\ |\ 1\ 0\ 0)$$
$$\hat{W}_5 = (0\ 0\ \text{-}1\ |\ \text{-}1\ 0\ 0)$$
$$\hat{W}_6 = (\text{-}1\ 0\ 0\ |\ 0\ 0\ 1)$$

$\prod_w$ is a full rank matrix.

For a general twist $\hat{T}$ Eqn. 4 is satisfied only when all the components of the twist are zero, i.e.,

$\Omega_X = \Omega_Y = \Omega_Z = V_X = V_Y = V_Z = 0$

It shows that the arrangement of the three vee grooves along the cube's edges is an exactly constrained design.

2.2.2 Case 2. Vee grooves on orthogonal planes of a cube and parallel to the axes

In this case, vee grooves are placed on orthogonal planes XY, YZ, XZ, and parallel to the X, Y, Z-axis respectively and pass through the middle of the face, i.e., the z-axis is parallel to the X, Y, Z-axis. α = β = ϒ = 0° and $\theta = 90°$ as shown in Fig. 4.

Wrenches for case 2 are given by

$$\begin{aligned}
\widehat{W}_1 &= \left(\frac{-1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\ 0 \middle|\ \frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\right)\\
\widehat{W}_2 &= \left(\frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\ 0 \middle|\ \frac{1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\right)\\
\widehat{W}_3 &= \left(\frac{-1}{\sqrt{2}}\ 0\ \frac{-1}{\sqrt{2}}\ \middle|\ \frac{-1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\right)\\
\widehat{W}_4 &= \left(\frac{-1}{\sqrt{2}}\ 0\ \frac{1}{\sqrt{2}} \middle|\ \frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\right)\\
\widehat{W}_5 &= \left(0\ \frac{-1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}} \middle|\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}}\right)\\
\widehat{W}_6 &= \left(0\ \frac{1}{\sqrt{2}}\ \frac{-1}{\sqrt{2}} \middle|\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\right)
\end{aligned} \tag{11}$$

The rank of constraint space matrix $\prod_w$ is six.
Eq. 4 is satisfied when all the components of the twist $\hat{T}$ are zero, i.e., $\Omega_X = \Omega_Y = \Omega_Z = V_X = V_Y = V_Z = 0$

It shows that the given arrangement is a completely constrained design.

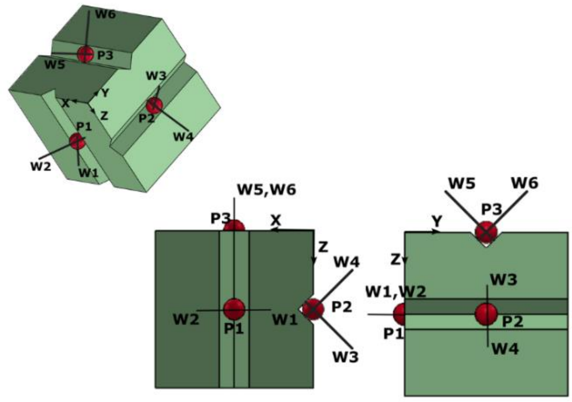

Figure 4. A physical arrangement of the body constrained by the three pairs of spherical balls and vee groove on the surfaces of a cube

2.2.3 Case 3. Vee grooves on the face diagonals of a cube (Y-configuration)

In this case, all vee grooves are aligned with the face diagonals of the orthogonal plane passing through the Origin, i.e., the z-axis is inclined at an angle 45° with each X, Y, Z axes on planes XY, YZ, and XZ, respectively.
In special case α = β = ϒ = 45° and $\theta = 90°$ as shown in Fig. 5.

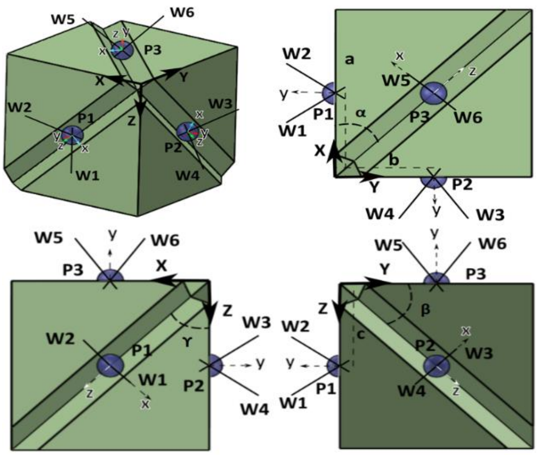

Figure 5. A physical arrangement of the body is constrained by the three pairs of spherical balls and vee groove on the face diagonals of a cube

Wrenches for case 3 are

$$\begin{aligned}
\widehat{W}_1 &= \left(\ \frac{-1}{2}\ \frac{-1}{\sqrt{2}}\ \frac{1}{2} \middle| \frac{1}{\sqrt{2}} - 1\ \frac{-1}{\sqrt{2}}\ \right)\\
\widehat{W}_2 &= \left(\ \frac{-1}{2}\ \frac{-1}{\sqrt{2}}\ \frac{-1}{2} \middle| \frac{1}{\sqrt{2}}\ 1\ \frac{-1}{\sqrt{2}}\ \right)\\
\widehat{W}_3 &= \left(\ \frac{-1}{\sqrt{2}}\ \frac{1}{2}\ \frac{-1}{2} \middle| - 1\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \right)\\
\widehat{W}_4 &= \left(\ \frac{-1}{\sqrt{2}}\ \frac{-1}{2}\ \frac{1}{2} \middle|\ 1\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \right)
\end{aligned} \tag{12}$$

$$\begin{aligned}
\widehat{W}_5 &= \left(\ \frac{1}{2}\ \frac{-1}{2}\ \frac{-1}{\sqrt{2}} \middle| \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \text{-}1\ \right)\\
\widehat{W}_6 &= \left(\ \frac{-1}{2}\ \frac{1}{2}\ \frac{-1}{\sqrt{2}} \middle| \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ \ \text{-}1\right)
\end{aligned}$$

The rank of constraint space matrix $\prod_w$ is six.
Eqn. 4 is satisfied when all the components of the general twist $\hat{T}$ is zero, i.e., $\Omega_X = \Omega_Y = \Omega_Z = V_X = V_Y = V_Z = 0$

It shows that the arrangement provides a completely constrained design.

2.2.4 Case 4. Vee grooves on the face diagonals of a cube (delta-configuration)

In this case, all vee grooves are aligned with the second face diagonals of the orthogonal plane that is perpendicular to the face diagonal passing through the Origin, i.e., the z-axis is inclined at an angle -45° with each X, Y, Z axes on planes XY, YZ, and XZ, respectively.
In special case α = β = ϒ = -45° and $\theta = 90°$ as shown in Fig. 6

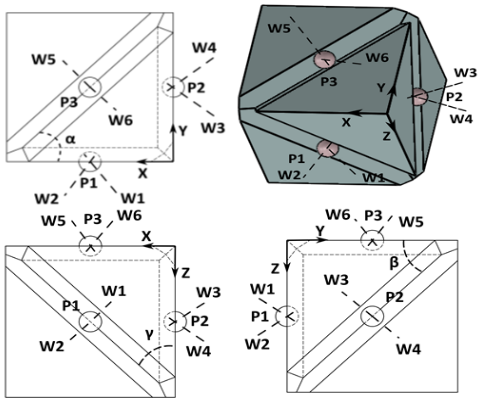

Figure 6. A physical arrangement of the body is constrained by the three pairs of spherical balls and vee groove on the face diagonals of a cube non intersecting at Origin

Wrenches for case 4 are given by

$$\begin{aligned}
\widehat{W}_1 &= \left(\frac{-1}{2}\ \frac{-1}{\sqrt{2}}\ \frac{-1}{2} \middle| \frac{1}{\sqrt{2}}\ 0\ \frac{-1}{\sqrt{2}}\right)\\
\widehat{W}_2 &= \left(\frac{1}{2}\ \frac{-1}{\sqrt{2}}\ \frac{1}{2} \middle| \frac{1}{\sqrt{2}}\ 0\ \frac{-1}{\sqrt{2}}\right)\\
\widehat{W}_3 &= \left(\frac{-1}{\sqrt{2}}\ \frac{-1}{2}\ \frac{-1}{2}\ \middle|\ 0\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\right)\\
\widehat{W}_4 &= \left(\frac{-1}{\sqrt{2}}\ \frac{1}{2}\ \frac{1}{2} \middle|\ 0\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\right)\\
\widehat{W}_5 &= \left(\frac{-1}{2}\ \frac{-1}{2}\ \frac{-1}{\sqrt{2}} \middle|\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ 0\right)\\
\widehat{W}_6 &= \left(\frac{1}{2}\ \frac{1}{2}\ \frac{-1}{\sqrt{2}} \middle|\ \frac{-1}{\sqrt{2}}\ \frac{1}{\sqrt{2}}\ 0\right)
\end{aligned} \tag{13}$$

The rank of constraint space matrix $\prod_w$ is five.
From Eq. 4. we get $V_X = V_Y = V_Z = 0$, and
$\Omega_x = \Omega_y = \Omega_z = \Omega$
therefore, the general twist for the given case is
$\hat{T} = (\Omega\ \Omega\ \Omega\ |\ 0\ 0\ 0)$
It can be further written as one independent twist as
$\hat{T}_1 = (1\ 1\ 1|\ 0\ 0\ 0)$

3. Results and discussion

Based on the above constraint analysis of three pairs of ball and vee grooves, we have designed 3-D kinematic clamps using cad software and fabricated them using the 3D printing method. The top part has three spherical balls which contact three vee grooves on the bottom part. The bottom part is a section of a cube that makes the base. A set of three vee grooves are made on face diagonals (Y and delta), along edges, and on the faces of the cube as various design cases.

Case 1 has three vee grooves on the edges of the cube, and they all intersect at the apex. 3D printed prototype of the kinematic clamp is shown in Fig. 7.

Case 2 has three vee grooves on the face diagonal of the cube, and they all intersect at the apex. 3D printed prototype of the kinematic clamp is shown in Fig. 8.

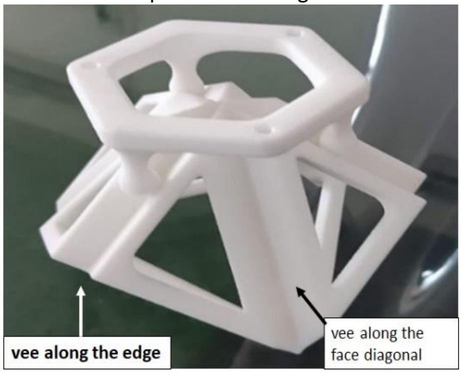

Figure 7. 3D printed prototype of a 3-D kinematic clamp with balls on vee along the edges of the cube (Case 1)

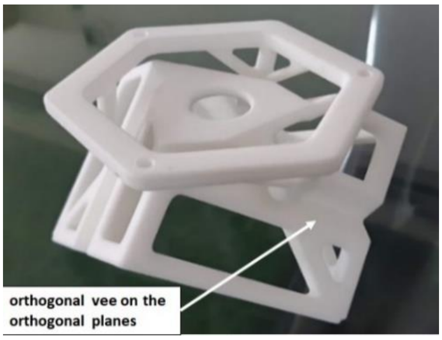

Figure 8. 3D printed prototype of a 3-D kinematic clamp with balls on the orthogonal vee on the orthogonal planes (Case 2)

Case 3 has three vee grooves on the three orthogonal faces of the cube, and they are orthogonal to each other. 3D printed prototype of the kinematic clamp is shown in Fig. 9.

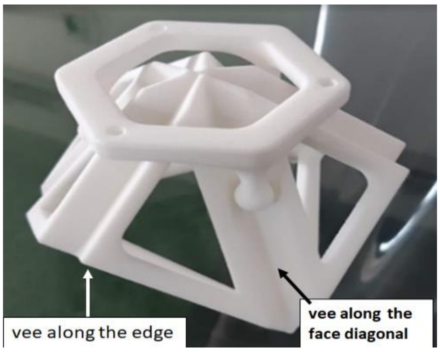

Figure 9. 3D printed prototype of a 3-D kinematic clamp with balls on vee grooves along the face diagonals (Case 3)

Case 4 has three vee grooves on the three orthogonal faces of the cube (delta-configuration), and they do not intersect at the Origin, which is shown in Fig. 6. it has six contact points, but not all DOFs are constrained, so this case represents the over constrain the design.

The kinematic clamps used in the analysis are exactly constrained and over-constrained, and they can be verified by inspection also. However, a general case may not be trivial and requires an analytical method to check if it is exactly over-constrained. Screw algebra provides an alternate approach to investigate, using the constraint line approach. Compliant mechanisms may be analysed similarly using screw algebra.

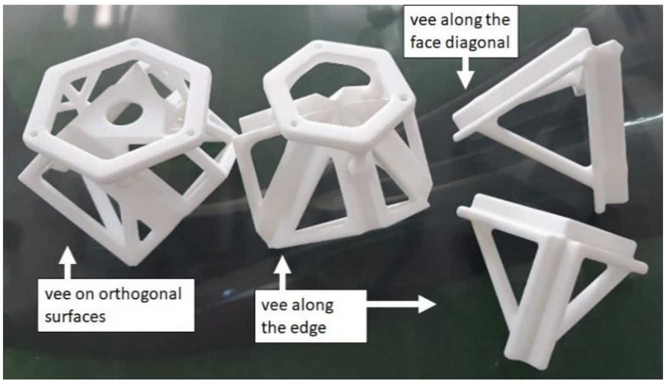

Figure 10. 3D printed prototype of 3-D kinematic clamps, vee along the edge, vee along the face diagonal, vee on orthogonal surfaces

4. Conclusion

We used the screw theory to perform constraint pattern analysis for four different 3-D kinematic clamps using three pairs of vee grooves and spherical ball contact on three orthogonal surfaces. Wrenches are obtained along the constraint lines for each case. The constraint space matrix is full rank for three cases, and therefore, the designed 3-D kinematic clamps are exactly constrained. For the fourth case, the constraint space matrix is not a full rank; hence this case is not exactly constrained. Prototypes are developed and fabricated using 3d printing. Screw algebra can be used for constraint analysis, and designs can be verified for any general case where vee grooves can be placed on arbitrary surfaces. This approach allows various design choices in a constrained or desired space.

References

[1] Slocum, A.H., 1988. Kinematic couplings for precision fixturing – Part I: Formulation of design parameters. *Precision Engineering*, *10*(2), pp. 85-91.

[2] Slocum, A.H., 1992. Design of three-groove kinematic couplings. *Precision Engineering*, *14*(2), pp. 67-76.

[3] Hale, L.C., 1999. *Principles and techniques for designing precision machines*. PhD thesis. MIT, USA.

[4] Hale, L.C. and Slocum, A.H., 2001. Optimal design techniques for kinematic couplings. *Precision Engineering*, *25*(2), pp. 114-127.

[5] Slocum, A., 2010. Kinematic couplings: A review of design principles and applications. *International Journal of Machine Tools and Manufacture*, *50*(4), pp. 310-327.

[6] Blanding, D.L., 1999. *Exact constraint: machine design using kinematic principles*. American Society of Mechanical Engineers.

[7] Soemers, H. M. J. R., 2010, *Design Principles for Precision Mechanisms*, Enschede, Netherlands: T-Point Print, ISBN 978-90-365-3103-0.

[8] Khatait, J.P., Brouwer, D.M., Soemers, H.M., Aarts, R.G. and Herder, J.L., 2013. Design of an experimental set-up to study the behavior of a flexible surgical instrument inside an endoscope. *Journal of medical devices*, *7*(3).

[9] Davidson, J.K. and Hunt, K.H., 2004. *Robots and Screw Theory: Applications of Kinematics and Statics to Robotics*. Oxford University Press, Oxford, England. (ISBN 0-19-856245-4).

[10] Su, H.J., Dorozhkin, D.V. and Vance, J.M., 2009. A screw theory approach for the conceptual design of flexible joints for compliant mechanisms. ASME. J. Mechanisms Robotics. 1(4): 041009 (8 pages).

[11] Su, H.J., Zhou, L. and Zhang, Y., 2013. Mobility analysis and type synthesis with screw theory: from rigid body linkages to compliant mechanisms. In *Advances in Mechanisms, Robotics and Design Education and Research.* pp. 67-81. Springer International Publishing Switzerland.