Mechanisms Design Using Kinematic Chains of Group-IV-D, E and F

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Abstract. This study checks the isomorphism among 10 Links, 13 Joints, Single degree of freedom Kinematic Chains of Group IV-D,E and F using a Joint-Joint [JJ] matrix method. Two identification numbers or structural invariants namely 'sum of the absolute values of the characteristic polynomial coefficients' [SCPC] and 'maximum absolute value of the characteristic polynomial coefficient' [MCPC] are applied for each matrix with the help of MATLAB to check isomorphism in the mechanism kinematic chains. The study is helpful for new researchers / design engineers and scientist in selecting the best kinematic chain to perform the predecided task at the conceptual stage of design. The study is explained with the help of examples of planar kinematic chain having simple joints.

Key words. Mechanisms, Kinematic Chains; Isomorphism; Degree of Freedom.

I. INTRODUCTION

A number of researchers have discussed structural synthesis in the earlier days. Chang, et.al. [1] proposed method is based on the eigen vectors and eigen values to identify isomorphism of mechanism kinematic chain. Mruthyunjaya [2] made an effort to develop a fully computerized approach for structural synthesis of kinematic chains. Agrawal and Rao [3] investigated a systematic method of analysis of the mobility properties of the kinematic chains by its loop freedom matrix and its permanent function which are used to identify it. Sethi and Agrawal [4] proposed a classification scheme on the basis of structural properties. Madan and Jain [5] considered the kinematic chains-isomorphism, inversions and degree of similarity using the concept of connectivity. Rao [6] threw the light on the enumeration of distinct planar kinematic chains. Misti [7] presented the position analysis in polynomial form of planar mechanisms with Assur groups of class 3 including revolute and prismatic joints. Uicker and Raicu [8] presented a method for the identification and recognition of equivalence of kinematic chains. Later on, this method failed. Mruthyunjaya and Balasubramanian [9] proved that the method proposed by Uicker and Raicu [8] is not reliable. Shende and Rao [10] work on the problem of detection of isomorphism. Chu Jin-Kui and Cao Wei-Qing [11] proposed a method for identification of isomorphism among kinematic chains and inversions using Link's adjacent-chain-table. Yadav, et.al. [12] Proposed a computer aided detection method of isomorphism among kinematic chains and mechanisms using the concept of modified distance. Yadav, et.al.[13] presented a paper mechanism of a kinematic chain and the degree of structural similarity based on the concept of link path code'. Yadav, et.al.[14] presented a paper 'computer aided detection of isomorphism among binary chains using the link-link multiplicity distance concept. Rao [15] sued the application of fuzzy logic for the study of isomorphism, inversions, symmetry, parallelism and mobility in kinematic chains with some necessary and sufficient conditions. Kong, et.al. [16] Proposed a new method based on artificial neural network (ANN) to identify the isomorphism of the mechanism kinematic chain. Rao and Deshmukh [17] proposed method does not require any separate test for isomorphism in the generation of kinematic chains. He and Jhang [18] proposed a new method for detection of graph isomorphism based on the quadratic form. Tang and Liu [19] established a method 'the degree code' as a new mechanism identifier. Later on this method also failed. Zhao, et.al [20] put forward and more complete theory of degrees of freedom (DOF) for mechanisms. Hasan et al. [21] but the concept that these methods are based on seems to be unjustified as either link-link adjacency or joint-joint adjacency hardly differ in nature and are likely to fail at some stage or the other. Hasan [22],[23] proposed a new method in which kinematic chains are represented in the form of the Joint-Joint [JJ] matrix. Dargar et al. [24],[25] proposed Link adjacency value method to identify the isomorphism by calculating the first and second link adjacency values. Rizvi et al. [26] presented a new method for distinct inversions and isomorphism based on a link identity matrix and link signature.

II. THE JOINT-JOINT [JJ] MATRIX

This matrix is based upon the connectivity of the joints through the links and defined, as a square symmetric matrix of size n x n, where n is the number of Kinematic pairs (joints) in a kinematic chain.

$$[JJ] = \{L_{ij}\}_{n \times n} \qquad ------(1)$$

Where, L_{ij} {= Degree or Type of Link between ith and jth joints, those are directly connected,

off course, all the diagonal elements $L_{ii} = L_{jj} = 0$}

Note: Degree or type of link means: 2 for binary link, 3 for ternary link, 4 for quaternary link and so on.

III. METHODOLOGY

Two similar square symmetric matrices have the same characteristic polynomials. Plain kinematic chains of combination of binary, ternary, and other higher order links. These links are joined together by simple kinematic pairs or simple pin joints. An identification number is assigned to links. Therefore, a binary link has a value of two, ternary three, quarter nary four and so on. Link values are used to assigned values to [JJ] matrix and these are utilized to identify the layout of the kinematic chains. For detecting isomorphism in kinematic chains, [JJ] matrices are written and identification number (composite structural invariants) [SCPC] and [MCPC] for [JJ] matrix are calculated. If the structural invariants [SCPC] and '[MCPC] of the two or more kinematic chains are same then the kinematic chains are considered as isomorphic otherwise non-isomorphic.

IV. ILLUSTRATIVE EXAMPLE

We have two kinematic chains with 12 links, 16 joints, one degree of freedom shown in Figure 1 and Figure 2. Now, we have to check whether these two KCs are

isomorphic. [A] and [B] represent the [JJ] matrices for these KCs respectively.

The values of Identification Numbers (structural invariants are :

For KC shown in Figure 1: [SCPC] = 2.9971e+010 , [MCPC] =1.0219e+010 and

For KC shown in Figure 2: [SCPC] = 3.2201e+010, [MCPC] =1.1287e+010.

We note that KCs shown in Figure 1 and Figure 2 are non-isomorphic because the values of their identification numbers [SCPC] and [MCPC] are different for both the KCs. We Note that the author results are validated by using another method Chang [1] and Kong [16], already available in the literature.

$$A=\begin{bmatrix}
0 & 3 & 3 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
3 & 0 & 3 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 \\
2 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 0 \\
0 & 0 & 0 & 3 & 3 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 2 & 0 & 0 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 0 & 2 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 3 & 0 & 3 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 3 & 0 & 0 & 3 & 3 \\
0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 3 & 0 \\
0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 0 & 3 \\
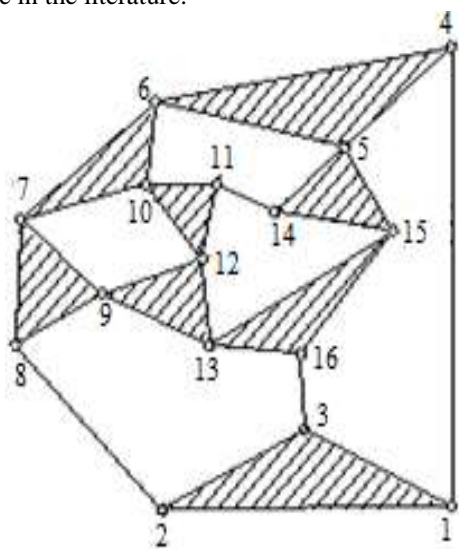0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 0
\end{bmatrix}$$

$$B=\begin{bmatrix}
0 & 3 & 3 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
3 & 0 & 3 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 \\
3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 \\
2 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 0 \\
0 & 0 & 0 & 3 & 3 & 0 & 3 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 3 & 3 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 3 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 0 & 0 & 0 & 0 & 3 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 3 & 3 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 0 & 2 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 3 & 3 & 0 & 3 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 3 & 0 & 0 & 3 & 3 & 0 \\
0 & 3 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 0 & 3 \\
0 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 3 & 0 & 3 & 0
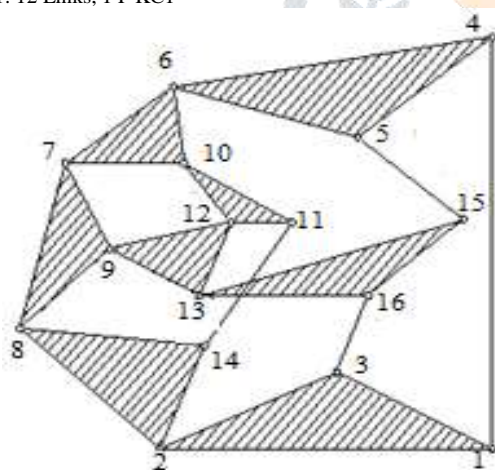\end{bmatrix}$$

Figure 1: 12 Links, 1 F KC1

Figure 2: 12 Links, 1 F KC2

V. RESULTS AND CONCLUSIONS

The structural invariants [SCPC] and [MCPC] are used as the identification number of the kinematic chains having simple joints. The detailed identification numbers (values of SCPC and MCPC) of all 1-dof kinematic chains up to 10-Links are with the author. These identification numbers are also capable to detect isomorphism among the kinematic chains with multiple joints too. The kinematic chains of 10 Links, 13 Joints, 1-dof Kinematic Chains Group 'IV D, E and F' are redrawn from Jensen [27] and given in Table 1D,1E and Table 1F. The identification Numbers of Kinematic Chains Group-IV D, E and F are given in Table 2. In the present study, a simple, efficient, and reliable Joint-Joint [JJ] method proposed by Hasan[22] is used for isomorphism identification. Using this methodology, the isomorphism of mechanisms kinematic chains can easily be identified and mechanisms determined. It incorporates all features of the kinematic chains and as such, violation o f the isomorphism test is rather difficult. The method has already been applied and found to be successful in distinguishing all known 16 kinematic chain of 8-links, 230 kinematic chain of 10-links having 1-F. The advantage is that they are very easy to compute using MATLAB software. It is not essential to determine both the structural invariants to compare two chains, only in case the [SCPC] is same then it is needed to determine [MCPC]for both kinematic chains. The [JJ] matrices can be written with very little effort, even by mere inspection of the chain. The proposed test is quite general in nature and can be used to detect isomorphism of not only planar kinematic chains of one degree of freedom, but also kinematic chains of multi degree of freedom.
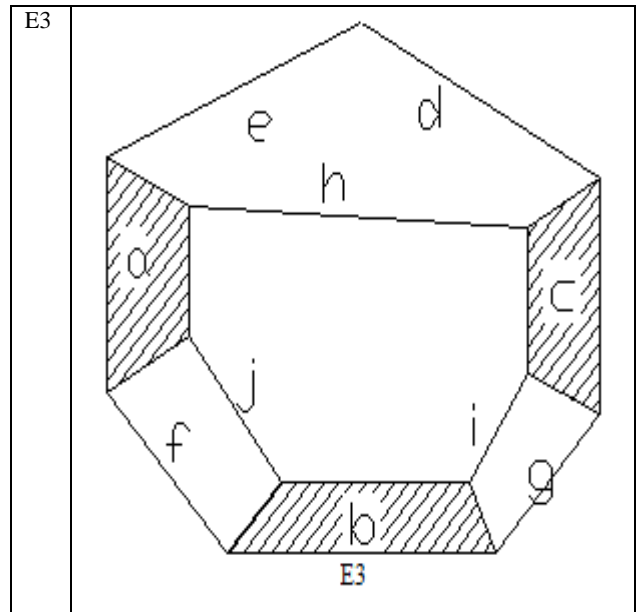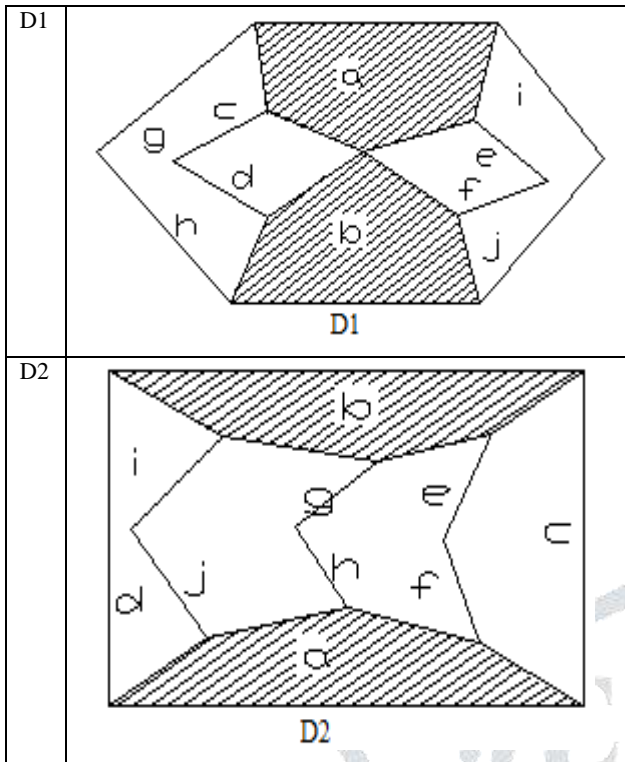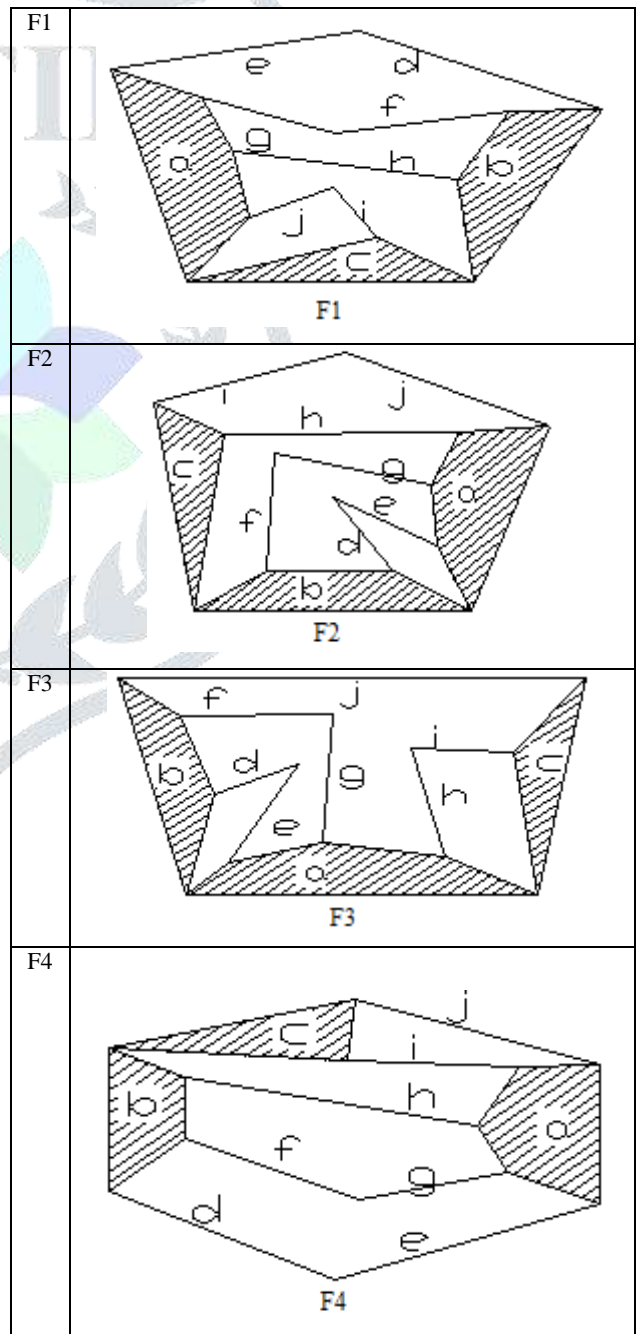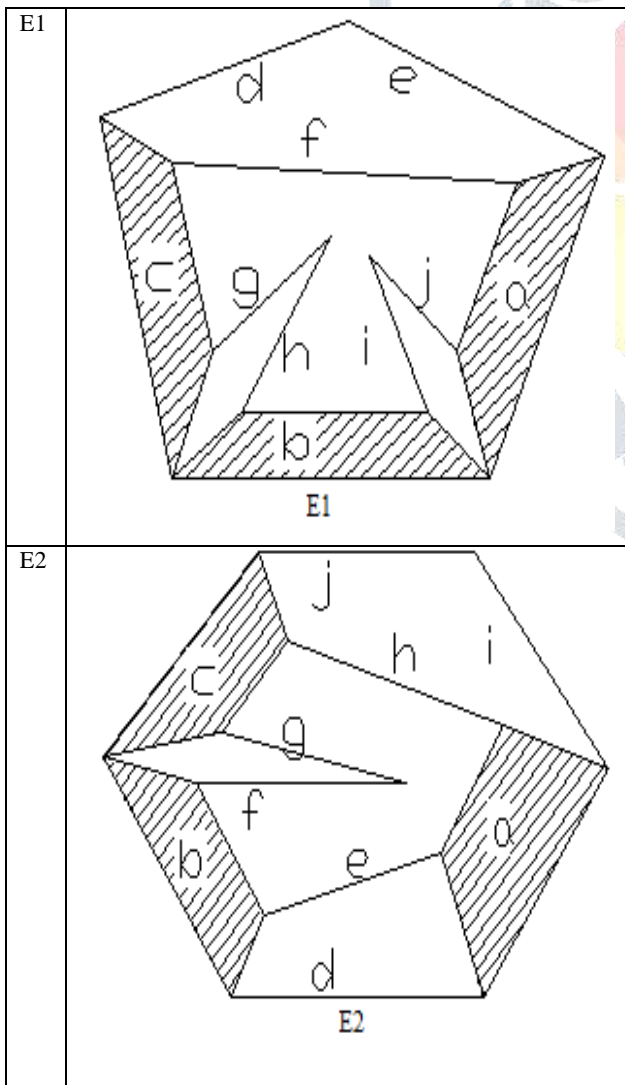
TABLE 1D
10 LINK, 13 JOINTS, 1F KC GROUP IVD

D1

D2

TABLE 1E
10 LINK, 13 JOINTS, 1F KC GROUP IVE

E1

E2

E3

TABLE 1F
10 LINK, 13 JOINTS, 1F KC GROUP IVF

F1

F2

F3

F4

F5

F6

F7

F9
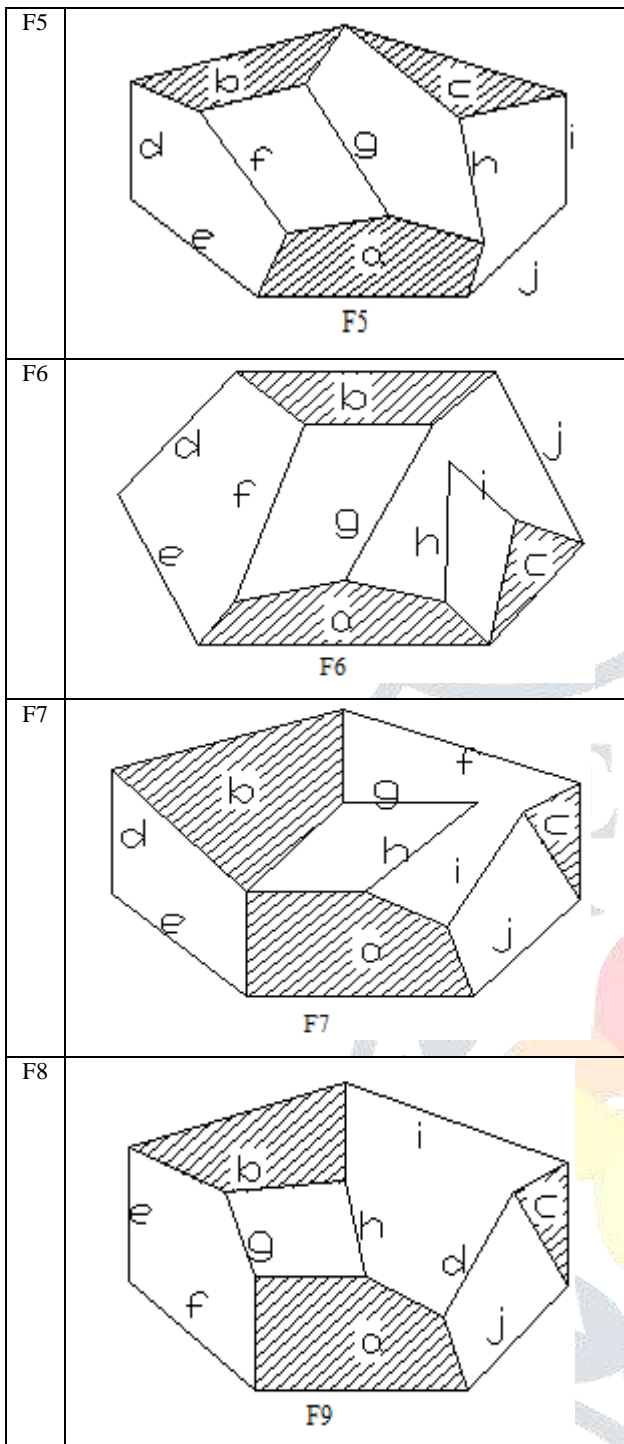
TABLE 2
STRUCTURAL INVARIANTS OF KCS GROUP IV D, E AND F

S.N.	KC	$n_5 n_4 n_3 n_2$	SCPC	MCPC
Structural Invariants of KCs GROUP IV D				
1	D1	2008	1.0071e+008	4.5427e+007
2	D2	2008	2.3121e+008	1.0077e+008
Structural Invariants of KCs GROUP IV E				
3	E1	0307	1.3726e+007	5.9228e+006
4	E2	0307	1.6797e+007	6.3078e+006
5	E3	0307	1.1802e+007	4.9592e+006
Structural Invariants of KCs GROUP IV F				
6	F1	1117	3.8452e+007	1.2259e+007
7	F2	1117	7.2174e+007	2.3745e+007
8	F3	1117	3.6131e+007	1.5192e+007
9	F4	1117	1.1376e+008	4.4208e+007
10	F5	1117	7.9142e+007	3.2904e+007
11	F6	1117	3.8505e+007	1.3984e+007
12	F7	1117	8.8718e+007	3.7513e+007
13	F8	1117	1.1202e+008	4.5708e+007

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