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A Least Path Matrix Concept to Detect Isomorphism in Planar Kinematic chain's

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Abstract*— In the early stage of mechanism design, it is helpful to have all possible kinematic chain with required number of links and degree of freedom. The mechanism will lead to systematic development of enumeration, identification, classification and detection of isomorphism among kinematic chains and mechanisms. Over the past several years much work has been reported related to isomorphism. A new method for detection of isomorphism based on generation of least path matrix concept, easy to compute and reliable is suggested in this paper. First we need to give joint number at each joint of kinematic chain on the basis of node number. Node number can be given as the ratio of number of parameters at particular node and the number of node at particular link. It is capable of detecting isomorphism in all types of planer kinematic chains. The method is unique in the sense that the kinematic chains and numerical strings presented represent the chains uniquely.
Keywords*— kinematic chain, mechanism, least path matrix, joint number, node number, isomorphism.

I. INTRODUCTION

Kinematic synthesis is an essential step at the first stage of designing a machine, as it represents creation of mechanism to achieve a desired set of motion characteristics. The study of kinematic structure of mechanism may be expected to lead to systematic development of the statics, kinematics or dynamics to a logical system of classification of mechanisms and mechanical systems and to foundation for the for the analysis of general mechanical system, involving a wider variety of components, and including both rigid body and elastic displacements. The bodies in kinematic chain may be relabelled through an orthogonal transformation of the adjacency matrix, woo [1] use an algorithm based on this approach to identify the kinematic chain increases, the number of possible orthogonal transformations of the adjacency matrix increases as n-factorial. Visual inspection of kinematic chain was the only available means for detecting isomorphs before woo's algorithm. Visual inspection is not always simple; often diagrams of identical kinematic chains can, at first sight, appear to be different. Ambekar and Agrawal [6] in this approach canonical number system is used to completely eliminate duplicate identification of kinematic chains. Canonical code can be decoded back to the canonical form of the adjacency matrix. In this paper author explain there is two types of canonical adjacency is possible one is maximum code – max code and other one is minimum code- min code. The method is applied in six link one degree of freedom kinematic chains (Watt's and Stephenson's chain). Wen-Miin Hwang et al[9] proposed a straightforward approach for the computer-aided structural synthesis of planar kinematic chains with simple joints, which consists of systematic generation of possible contracted link adjacency matrices, detection of degenerate chains and identification of isomorphic chains. A review of the significant method to test isomorphism is available in [13] and the following survey is largely based on that. We now consider the traditional methods of detecting isomorphism and their weaknesses, admitting that in the general case no efficient solution of the graph isomorphism problem has yet been found. Chang et al [19] new concept based on Eigenvalues and Eigenvector is used to detect isomorphism in planar kinematic chains. Adjacency Matrix is used to represent the kinematic chain. From adjacent matrix Eigenvalues and Eigenvectors is calculated and then isomorphic chains can identify. Cubillo and Wan [22] suggested new procedure to identify isomorphism among kinematic chains. With this new procedure, it is only necessary to compare Eigen values and several Eigen vectors of adjacent matrices of isomorphic kinematic chains to identify the isomorphic chains. Ali et al [26] proposed new method to identify the distinct mechanisms from a given kinematic chain. The Kinematic chains are represented in the form of Joint-Joint matrices. Two structural invariants, which are the sum of the absolute characteristic polynomial coefficients and maximum absolute value of the characteristic polynomial coefficients, are used as the composite identification number of a kinematic chain and mechanisms. The method is capable of detecting isomorphism in all types of planar kinematic chains.

II. THEORY

The following definitions are to be clearly applying in the method.

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A. Node Number (NN)

Node value is assigned as the ratio of number of parameters at particular node and the number of node at particular link is node value.

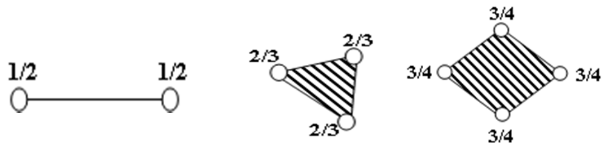

Fig. 1 Node values of binary link, ternary link, quaternary link

B. Joint Number (JV):- A joint value is a numerical value and defined as a multiplication of node connecting at a particular joint.

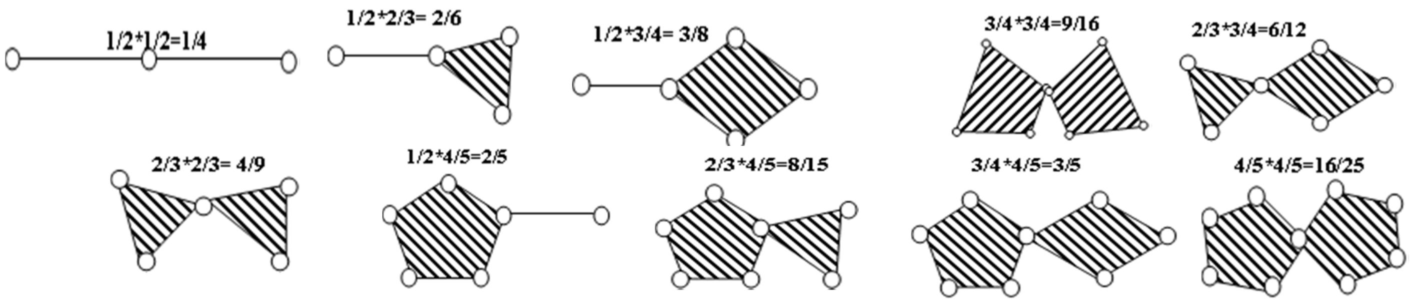

Fig.2 Joint values of all possible combination of links

C. Least Path Matrix (LPM)

Least path matrix is a square matrix. Least path matrix is formed on the basis of sum of least distance between joint numbers of the two links.

D. Kinematic link value (KLV)

The kinematic link value is the sum of the each elements of each row or column of least path matrix (LPM) will give a particular value. This value is termed as kinematic link value for that particular link.

E. Kinematic link string (KLS)

Kinematic link string refers to elements of particular row or column of least path matrix taken in ascending order.

F. Kinematic chain string (KCS)

Kinematic chain string is the sum of all the kinematic link value of particular chain along with all the elements of the least path matrix will give the kinematic chain string for that particular chain.

III. ISOMORPHISM

An isomorphism is a similarity of the processes or structure of one kinematic chain to those of another, be it the result of imitation or independent development under similar constraints. The method involves a parametric approach for detection of isomorphism and inversions. The method is explained using Watt and Stephenson’s chain. A least distance matrix (LDM) is formed using the values on the basis of the parameter. Watt chain is shown in fig.3 Link A& D are ternary link and link B, C, D & E are binary link. Each node of binary link is assigned a node value”1/2”and for ternary link joint value”2/3” is assigned. Also quaternary link “3/4" respectively.

For simplicity of calculation a non fractional value is assigned to each joint value on the basis of taking L.C.M. of joint values by which we can take same denominator for all joint value for various links connectivity.

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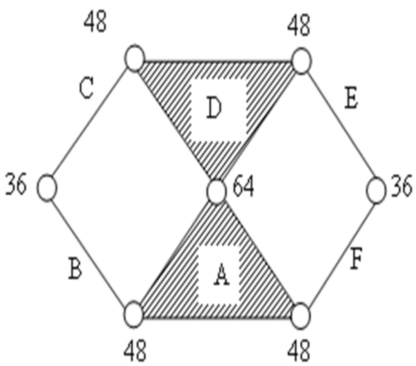


A least path matrix for watt chain fig.3:-

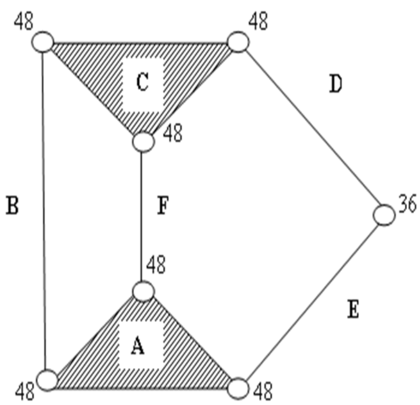
LINK	A	B	C	D	E	F	K.L.V.
A	0	48	84	64	84	48	**328**
B	48	0	36	84	132	96	**396**
C	84	36	0	48	96	132	**396**
D	64	84	48	0	48	84	**328**
E	84	132	96	48	0	36	**396**
F	48	96	132	84	36	0	**396**
							2240

Fig.3 watt chain with joint number

Thus at a node joining a binary link and binary link ,binary link and ternary link and ternary link and ternary link a node value will be assigned as 1/4,2/6,4/9 (2/3, joint value of ternary link and 1/2, joint value of binary link) as shown in fig.3. As shown in the matrix, for Watt chain, ternary link A is connected to binary link B and the node value is assigned “48”. For connectivity between link A and link C a shortest distance is considered i.e., 48+36=84. Similarly for connectivity between link A and link D the joint value will be “64” and so on. A 6*6 matrix will be formed for a six link watt chain.

Kinematic link string (KLS) for link A, B, C, D, E & F are: - [0, 2(48), 64, 2(84)],[0,36,48,84,96,132], [0, 36, 48, 84,96,132] ,[0, 2(48), 64, 2(84)] , [0, 36, 48, 84,96,132] & [0, 36, 48, 84,96,132] respectively.

Watt chain as show in fig.3 the kinematic link value (KLV) for link A, B, C, D, E & F are: - 328,396,396,328,396 and 396 respectively & kinematic chain string (KCS) for Watt chain are 2240, 2 [2(36), 4(48), 64, 4(84), 2(96), 2(132)].Further this method is applied in Stephenson chain fig.4.



A least path matrix for Stephenson chain fig.4

LINK	A	B	C	D	E	F	K.L.V.
A	0	48	96	84	48	48	**324**
B	48	0	48	96	96	96	**384**
C	96	48	0	48	84	48	**324**
D	84	96	48	0	36	96	**360**
E	48	96	84	36	0	96	**360**
F	48	96	48	96	96	0	**384**
							2136

Fig.4 Stephenson chain with joint number

Kinematic link String (KLS) for link A, B, C , D , E & F are: - [0, 3(48), 84, 96] , [0, 2(48), 3(96)] , [0, 3(48), 84, 96], [0, 36, 48, 84,2(96)] , [0, 36, 48, 84,2(96)], [0, 2(48), 3(96)] respectively. From above values of strings it is clear that link A & C will have the same inversion, link B & F will have the same inversions, link D & E will have the same inversions.

Kinematic link Value (KLV) for link A, B, C, D, E & F are: 324,384,324,360,360and 384 respectively. Also the sum of all the kinematic link values (KLV’s) of a particular chain will give the kinematic chain string (KCS) for Stephenson chain is 2136, 2[36, 6(48), 2(84), 6(96)].

A comparative study of watt chain and Stephenson chain on the basis of kinematic chain string (KCS) both chain are non isomorphic kinematic chain.

Consider Counter Example appeared in Reference [5] & Reference [9] chains shown in Fig.5, fig.6, fig.7, fig.8, fig.9 and fig.10 these chains have a different kinematic chain string (KCS) hence they are non-isomorphic.

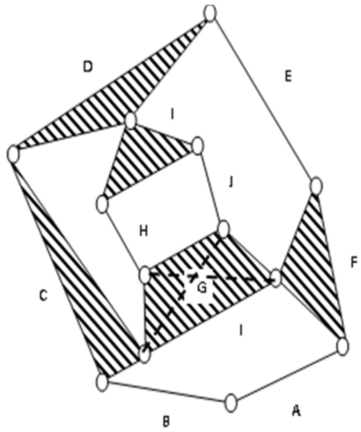


Fig.5 ten link one degree of freedom kinematic chain

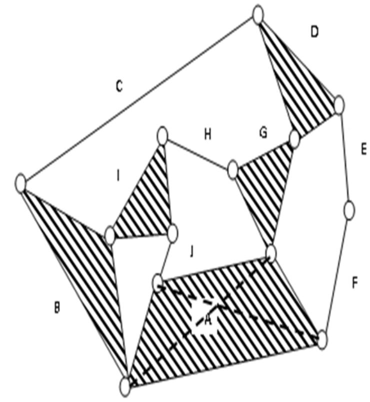


Fig.6 ten link one degree of freedom kinematic chain

Above are two kinematic chains with ten bars, 13 joints, and single degree-of-freedom (Fig.5 & fig.6)
Kinematic chain string (KCS) for chain shown in fig.5 is 9920, 2[36, 6(48),2(54),2(64),2(72), 2(84), 2(96),102, 108,5(112), 3(120),4(126),128, 2(132), 144,3(160),166, 4(174),176,208]
Kinematic chain String (KCS) for chain shown in fig.6 is 9544,2[36,7(48),2(54),2(64), 2(72),84,5(96),102, 108, 6(112), 120,3(126),132,4(144),156,4(160),174,190,208]
The method reports that chains in the fig.5 & fig.6 are non-isomorphic as the kinematic chain String (KCS) are different for both the kinematic chain. Note that, according to T.S. Mruthyunjaya, H.R. Balasubramaniam1987 [5], these chains are isomorphic but after that many researchers proved that these chains are non-isomorphic.

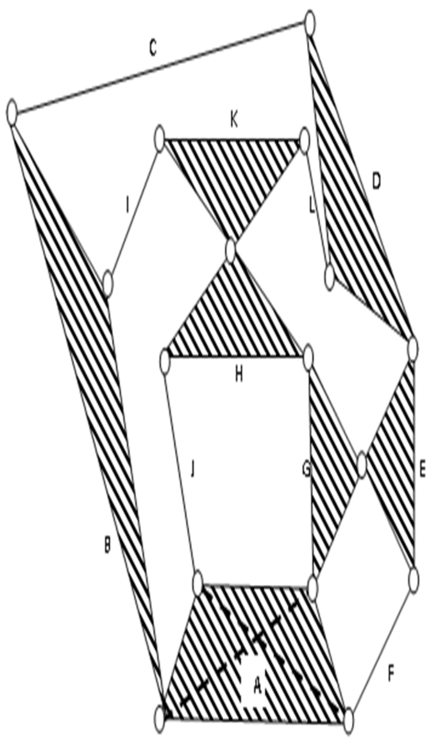


Fig.7 twelve link one degree of freedom kinematic chain

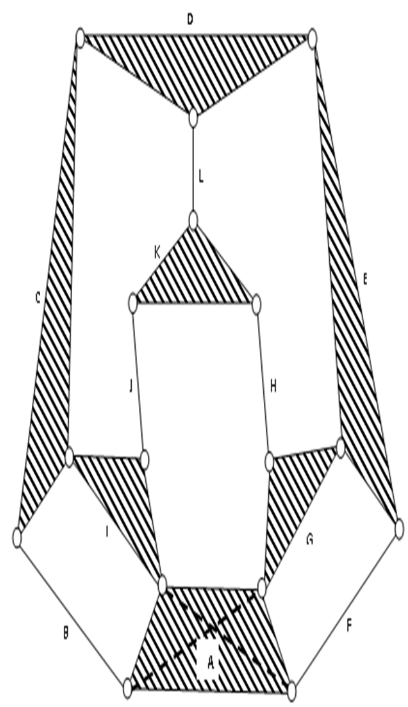


Fig.8 twelve link one degree of freedom kinematic chain

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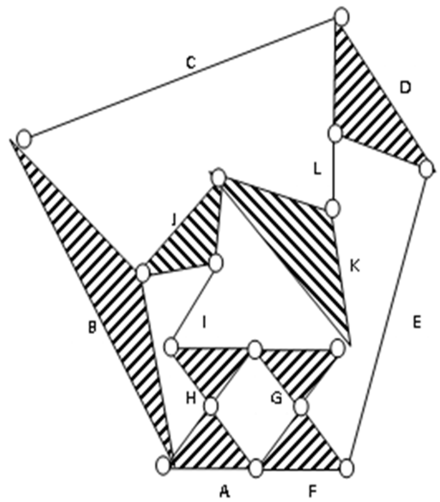

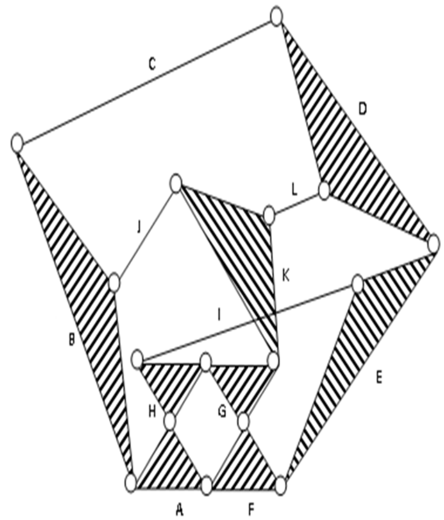

Fig.9 twelve link one degree of freedom kinematic chain

Fig.10 twelve link one degree of freedom kinematic chain

Fig.7, fig.8, fig.9, fig.10 are four kinematic chains with 12 bars, single degree-of-freedom.

Kinematic chain string for chain shown in fig.7 is 16128, 2[8(48), 8(64), 7(96), 10(112), 9(128), 6(144), 5(160), 4(176), 3(192), 4(208), 2(224)].

Kinematic chain string for chain shown in fig.8 is16160, 2[8(48), 8(64), 7(96), 10(112), 9(128), 3(144), 8(160), 8(176), 3(208), 2(224)].

Kinematic chain string for chain shown in fig.9 is15952 2[8(48), 2(54), 2(72), 6(96), 4(64), 2(102), 8(112), 2(120), 4(144), 2(126), 3(128), 8(160), 2(166), 2(174), 3(176), 4(208), 2(156), 214, 108].

Kinematic chain string for chain shown in Fig-10 is15816, 2[8(48), 2(54), 4(64), 2(72), 6(96), 2(102), 108, 8(112), 2(120), 2(126), 3(128), 7(144), 2(156), 6(160), 166, 168, 4(174), 4(208), 214]

A comparative study of twelve link one degree of freedom kinematic chains on the basis of kinematic chains string kinematic chains are said to be non isomorphic chain.

IV. INVERSION

An inversion is created by grounding a different link in the kinematic chain. The motions resulting from each inversion can be quite different, but some inversions of a linkage may yield motions similar to other inversions of the same linkage. In these cases only some of the inversions may have distinctly different motions. We will denote the inversions which have distinctly different motions as distinct inversions.

In order to know the distinct inversions of a chain, it is necessary to compare the kinematic link string (KLS) of all the links. If the strings are identical, the corresponding inversions are identical, otherwise distinct. A comparative study of Watt & Stephenson chain shows that Watt chain has 2 inversions and Stephenson chain has 3 inversions.

TABLE I

KINEMATIC LINK VALE AND KINEMATIC LINK STRING FOR WATT CHAIN FIG.3

Link	Kinematic Link Value (KLV)	Kinematic Link String (KLS)
A	328	[0, 2(48), 64, 2(84)]
B	396	[0,36,48,84,96,132]
C	396	[0, 36, 48, 84,96,132]
D	328	[0, 2(48), 64, 2(84)]
E	396	[0, 36, 48, 84,96,132]
F	396	[0, 36, 48, 84,96,132]

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TABLE III

DISTINCT INVERSION OF WATT CHAIN FIG.3

Distinct links	Kinematic Link Value (KLV)	Kinematic Link String (KLS)	Distinct Inversion
(B,C,E,F)	396	[0, 36, 48, 84,96,132]	2
(A,D)	328	[0, 2(48), 64, 2(84)]	

TABLE IIIII

KINEMATIC LINK VALE AND KINEMATIC LINK STRING FOR STEPHENSON CHAIN FIG.4

Links	LINK VALUE (LV)	LINK STRING (LS)
A	324	[0, 3(48), 84, 96]
B	384	[0, 2(48), 3(96)]
C	324	[0, 3(48), 84, 96]
D	360	[0, 36, 48, 84,2(96)]
E	360	[0, 36, 48, 84,2(96)]
F	384	[0, 2(48), 3(96)]

TABLE IVV

DISTINCT INVERSION OF STEPHENSON CHAIN FIG.4

Distinct links	Kinematic Link Value (KLV)	Kinematic Link String (KLS)	Distinct Inversion
(A,C)	324	[0, 3(48), 84, 96]	3
(B,F)	384	[0, 2(48), 3(96)]	
(D,E)	360	[0, 36, 48, 84,2(96)]	

The proposed concept is applied to planar kinematic chains. As per the earlier work and result there exist 5, 71, 253, 684, 1834 inversion for six link one degree of freedom, eight link one degree of freedom, nine link two degree of freedom, ten link three degree of freedom and ten link of one degree of freedom kinematic chains. Kinematic link value & kinematic link string for all possible distinct inversion for eight link one degree of freedom kinematic chain as shown in appendix I.

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Chain No.	Distinct Link	Kinematic Link Value (KLV)	Kinematic Link String (KLS)	Kinematic Chain String (KCS)	Distinct Inversion
1	(A,D,E,H) (B,C,F,G)	628 744	43,2(64),79,107,128,143 36,43,79,107,143,150,186	2[2(36),4(43),4(64),4(79),4(107),2(128),4(143), 2(150),2(186)]	2
2	(A,B,E,F) (C,D,G,H)	612 712	48,2(64),84,2(112),128 36,48,84,2(112),2(160)	2[2(36),4(48),4(64),4(84),8(112),2(128),4(160)]	2
3	(A,C) (B,H) (D,G) (E,F)	644 736 612 748	2(48),64,96,112,128,148 2(48),96,2(112),2(160) 48,2(64),84,2(112),128 36,48,84,112,148,2(160)	2[36,6(48),3(64),2(84),2(96), 6(112),2(128),2(148),4(160)]	4
4	(A) (B) (C) (D) (E) (F) (G) (H)	584 644 608 616 684 680 608 736	2(48),64,84,96,112,132 2(48),2(96),2(112),132 2(48),64,2(96),112,144 48,2(64),84,2(112),132 36,48,84,2(112),132,160 36,48,84,96,112,144,160 48,2(64),96,3(112) 2(48),96,2(112),2(160)	2[36,6(48),3(64), 2(84),4(96), 7(112),2(132),144,2(160)]	8
5	(A,G) (B,E) (C,D) (F,H)	640 584 652 708	48,2(64),96,2(112),144 2(48),64,84,96,112.132 36,48,84,96,112,132,144 2(48),96,2(112),132,160	2[36,7(48),2(84),4(96),5(112), 3(132),2(144), 160]	4
6	(A,C) (B,D) (E) (F,G) (H)	640 612 676 652 676	2(48),64,2(96),2(144) 2(48),64,84,128,144 2(48),2(96),112,132,144 36,48,84,96,112,132,144 2(48),2(96),112,132,144	2[36,6(48),3(64),2(84),5(96), 4(112),128,2(132),4(144)]	5
7	(A,B,C,D) (E,F,G,H)	640 736	2(48),64,2(112),96,160 2(48),96,2(112),2(160)	2[8(48),2(64),4(96),8(112), 6(160)]	2
8	(A,B,C,D) (E,F,G,H)	576 672	2(48),64,2(96),2(112) 2(48),2(96),2(112),160	2[8(48),2(64),8(96),8(112), 2(160)]	2
9	(A,D) (B) (C) (F,G) (E) (H)	608 576 608 640 672 704	2(48),64,2(96),112,144 3(48),3(96),144 48,2(64),96,3(112) 2(48),3(96),112,144 2(48),2(96),2(112),160 2(48),2(96),112,144,16	2[7(48),2(64), 9(96),5(112), 3(144),160]	6

			0		
10	(A) (B,C) (D,H) (E,G) (F)	552 618 684 738 672	2(54),2(72),2(90),120 2(48),72,84,96,126,144 36,54,84,108,126,132,144 36,48,90,96,2(144),180 2(48),2(96),120,2(132)	2[2(36),4(48),2(54),2(72),2(84), 2(90),3(96),120,2(126),2(132), 4(144),180]	5
11	(A) (B) (C) (D) (E) (F) (G) (H)	516 660 686 606 618 734 682 670	3(54),2(90),72,102 36,54,84,2(108),126,144 36,48,90,96,112,144,160 2(48),64,84,102,112,148 48,64,72,84,2(112),126 36,48,90,112,2(144),160 36,54,84,2(108),144,148 48,54,96,2(108),112,144	2[2(36),3(48),3(54),64,72,2(84), 2(90),96,102,3(108),3(112),126, 3(144),148,160]	8
12	(A) (B,H) (C) (D) (E) (F) (G)	598 672 644 666 600 724 680	3(54),72,2(112),150 48,54,2(96),108,126,144 3(48),96,102,144,158 2(48),3(96),132,150 2(48),72,84,96,2(126) 36,48,96,112,3(144) 36,54,84,2(108),132,158	2[5(48),3(54),72,84,5(96),102, 2(108)112,2(126),132,3(144), 150, 158]	7
13	(A) (B) (C) (D) (E) (F,G) (H)	510 654 670 570 642 670 634	4(54),90,2(102) 36,54,84,2(108),156 36,48,90,96,112,2(144) 2(48),64,84,102,2(112) 2(48),64,102,2(112),156 48,54,96,2(108),112,144 48,54,96,3(108),112	2[36,4(48),4(54),84,64,90,2(96), 2(102),4(112),5(108),2(144),156]	7
14	(A) (B,F,G,H) (C,E) (D)	570 654 630 630	4(54),2(102),150 48,54,2(96),2(108),144 3(48),96,102,2(144) 2(48),4(96),150	2[6(48),4(54),7(96),2(102), 4(108),4(144),150]	4
15	(A,D) (B,C,E,F,G,H)	513 684	3(54),81,3(90) 36,54,90,2(108),2(144)	2[3(36),6(54),6(90),6(108), 6(144)]	2
16	(A,D) (B,C,E,F) (G,H)	504 648 648	4(54),2(90).108 36,54,90,3(108),144 2(54),5(108)	2[2(36),9(54),3(90),12(112), 2(144)]	3

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Total Inversion	**71**

TABLE V

V. CONCLUSIONS

This paper addresses a problem of detection of isomorphism and inversion in the planar kinematic chain. The concept for detection of isomorphism and inversion is based on connectivity of the link and the concept is successfully identify isomorphism and inversion with eight link one degree of freedom, nine link two degree of freedom, ten link three and ten link one degree of freedom. With the implementation of this concept the isomorphism of planar kinematic chains can easily be identified. This work shows an efficient and reliable methodology to find out inversion of a planar kinematic chain. Such method can also computerize and coding can be developed to reduce time and acquire results faster. The results are compared with past result and are in agreement.

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Appendix – I

Eight link one degree of freedom kinematic chains