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# Enumerating Kinematic Chains of 9 links and 4 degree of freedom using Software

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**ABSTRACT**

The present paper is another application of the maxcode algorithm. The applications of kinematic chains (Mechanisms) has lead to more scope in the structural synthesis of the same with the higher degrees of freedom. The interdisciplinary applications in almost every field as kinematic chain being the basic element has lead to the deep research in the enumeration area. The feasible chain has positive degree of freedom ,without ternary link, and open chain.The feasibility check is done through program code. The coding(Maxcode) methodology adopted for the enumeration of feasible, nonisomorphic, distinct kinematic chains has given an added advantage in the enumeration process by eliminating the infeasible, isomorphic chains during the process of enumeration. The present paper presents the methodology and the results of enumeration of nine link four degree of freedom kinematic chains.

***Keywords:*** Enumeration, Kinematic Chain, Assortments of links, links,degree of freedom, Maxcode.

## I. INTRODUCTION

Machine designers are working on the synthesis or enumeration of distinct kinematic chains unconsciously since time immemorial, Uicker and Raicu[1] proposed the characteristic polynomial, but the computations are rather tedious. A modification to the matrix notation was proposed by Mruthyunjaya and Raghavan, [2] with a view to permit derivation of all possible mechanisms from a kinematic chain and distinguishing the structurally distinct ones by, changing the concept of adjacency matrix. Rao and Raju [3], Rao[4] proposed the secondary Hamming Number Technique for the generation of planar kinematic chains which was accepted. Similarly Hwang and Hwang [5], A.C Rao and Pratap B. Deshmukh[6] Mruthyunjaya [7-9], also synthesized the kinematic chains by different methods. A major problem is faced these years has been the absence of a reliable and computationally efficient technique to pick the non-isomorphic chains. The reason why designers have been plodding through so many new routes instead of sticking to what ought to have been a 'straight-as-an-arrow' path is easy to visualize with an implied requirement of decodability.

Read and Corneil [10] remark that a good solution to the coding problem provides a good solution to the isomorphism problem , though, the converse is not necessarily true. This goes to suggest that a successful solution to the isomorphism problem can be obtained through coding. The concept of canonical numbers provide identification codes which are unique for structurally distinct kinematic chains. One important feature of canonical numbers is that they are decodable, and also promises a potentially powerful method of identifying structurally equivalent links and pairs in a kinematic chain. While describing a method of storing the details of adjacency matrix in a binary sequence, maxcode and mincode are the tools for the identification of kinematic chains. The test of isomorphism then reduces to the problem of comparing max/ mincodes of the two chains.

According to Ambekar and Agrawal [11,12] the concepts of maxcode and mincode were introduced as canonical number for the enumeration. For every kinematic chain of n-links, there are n! different ways of

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labeling the links and hence, n! different binary numbers are possible for the same chain. By arranging these n! binary numbers in an ascending order, two extreme binary numbers can be identified , as significant ones for the same chain. These two binary numbers are : the maximum number and minimum number designated , respectively as maxcode M(K) and mincode m(K) . Since M(K) and m(K) denotes two extreme values of binary numbers for a given kinematic chain , and each has a unique position in the hierarchical order and is easily recognized, they are called as canonical numbers. Again each binary number of a given kinematic chain corresponds to a particular adjacency matrix , and hence it also corresponds to a particular labeling scheme.

The algorithm was generated for the structural enumeration and identification of kinematic chains. [13]. The algorithm has been proved. The present paper discusses " the enumeration of kinematic chains of 9-linked four degree of freedom by maxcode algorithm".

Martins and Carboni [14] implemented an algorithm of connectivity calculation and they implemented a test for identification of improper kinematic chains, Martins et al. [15]. To the best of the authors' knowledge, the method proposed by Martins et al. [15] is the unique that enumerate only fractionated kinematic chains. Simoni et al. [16,17] for enumeration of mechanisms based on graph and group theory techniques. Sunkari and Schmidt's [18] implemented an efficient test for detection of improper planar kinematic chains. [19] R. Simoni et al. has given a review of the current status of enumeration of kinematic chains and mechanisms, i.e. number synthesis, and point out the discrepancies and some incorrect results of the methods found in literature.

The advantage of the presented results is that the ready availability of kinmatic chains in the dictionary form so that kinematic chains can be used as a basic element wherever needed. The coding method[13] give a unique, nonisomorphic distinct kinematic chain.

## II. MAXCODE ALGORITHM FOR ENUMERATION OF CHAINS [13]

Step 1: Listing all assortments of binary, ternary, etc. links in the chains for given N and F. Assuming any of the link (amongst the available) of highest degree, as link 1 and write down first row of UTAM to extract maximum possible number.

Step 2: The range of Maxcode is established i.e.upperlimit (MAXU) and lower limit(MAXL) is established.

MAXU – to link 1 connect all links of highest degrees from the remaining so as to produce feasible chains.

MAXL – To link 1 connect all binary links, so as to produce feasible chains,

Step 3: The range is then scanned for every digital number in it for generating feasible chain In the scanning process the following steps are adopted

Step 3a : MAXL value is selected and its decoding is done to establish a binary code.

Step 3b: From the binary code adjacency matrix is generated which represents the kinematic chain .

Step 3c : To discard the adjacency matrix which does not give feasible chain (by eliminating the adjacency matrix which forms 3-links loop or open chain )

Step 3d : Once the adjacency matrix is selected then maxcode labeling scheme is used to identify the Kinematic Chain.

It is done in following way :

Step $3d_1$ : For a single Kinematic Chain if number of schemes of labeling are existing they are printed.

Step $3d_2$: Then establishing the decimal code for each scheme of labeling and pick up only those having maximum value of decimal code for the same Kinematic Chain and that scheme of labeling is known as canonical scheme of labeling

Step 3e: A canonical matrix is derived from a canonical scheme of labeling of links of the given Kinematic chain which is unique for a given chain.

Step 3f : The test of isomorphism then reduces to the problem of comparing maxcodes of the two chains.

Step3g : Then Kinematic Chain is defined completely with the unique code (maximum)which is further checked for its existence in the earlier trails, if not then it is stored.

**The methodology is applied for the 9 – link four degree of freedom kinematic chains**

Listing of all combinations of n2, n3, n4 , etc which satisfy the conditions[13]. The table 1. shows the assortments of links for 9 linked two degree of freedom kinematic chains.

**Table 1**
**Assortments of links**

| *Number of Links(N)* | *Degree of Freedom(DF)* | *Number of Binary links (N2/ n2)* | *Number of Ternary links (N3/ n3)* | *Number of Quaternary links (N4/ n4)* | *Link assortment number* | *Number of Chains generated using proposed algorithm* |
|---|---|---|---|---|---|---|
| *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | | *(6)* |
| 9 | 4 | 8 | 0 | 1 | 9_4_8-0-1-0 | 2 |
| 9 | 4 | 7 | 2 | 0 | 9_4_7-2-0-0 | 8 |

From the above basic concept and using the algorithm of section 2, the enumeration of the 9 – link two degree of freedom kinematic chains has been done and explained in further sections

The input and output along with kinematic chains generated has been explained.

## III. INPUT FOR THE ASSORTMENT OF SL. NO. 1 IN TABLE 1. : 9_4_8-0-1-0

INPUT IS :

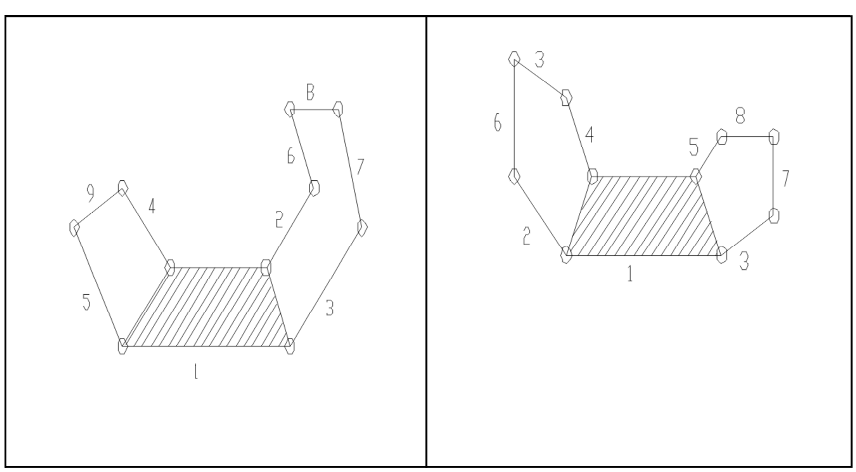
NUMBER OF LINKS (N) = 9; DEGREE OF FREEDOM (DF) = 4

N2 = 8; N3 = 0; N4 = 1; N5 = 0; N6 = 0

Output of the program : Shown in Table 2.

**TOTAL NO. OF VALID CHAINS ENUMERATED = 2**

**Table 2**
**Output for the assortment of : 9_4_8-0-1-0**



## IV. INPUT FOR THE ASSORTMENT OF SL. NO. 2 IN TABLE 1:9_4_7-2-0-0

INPUT IS :

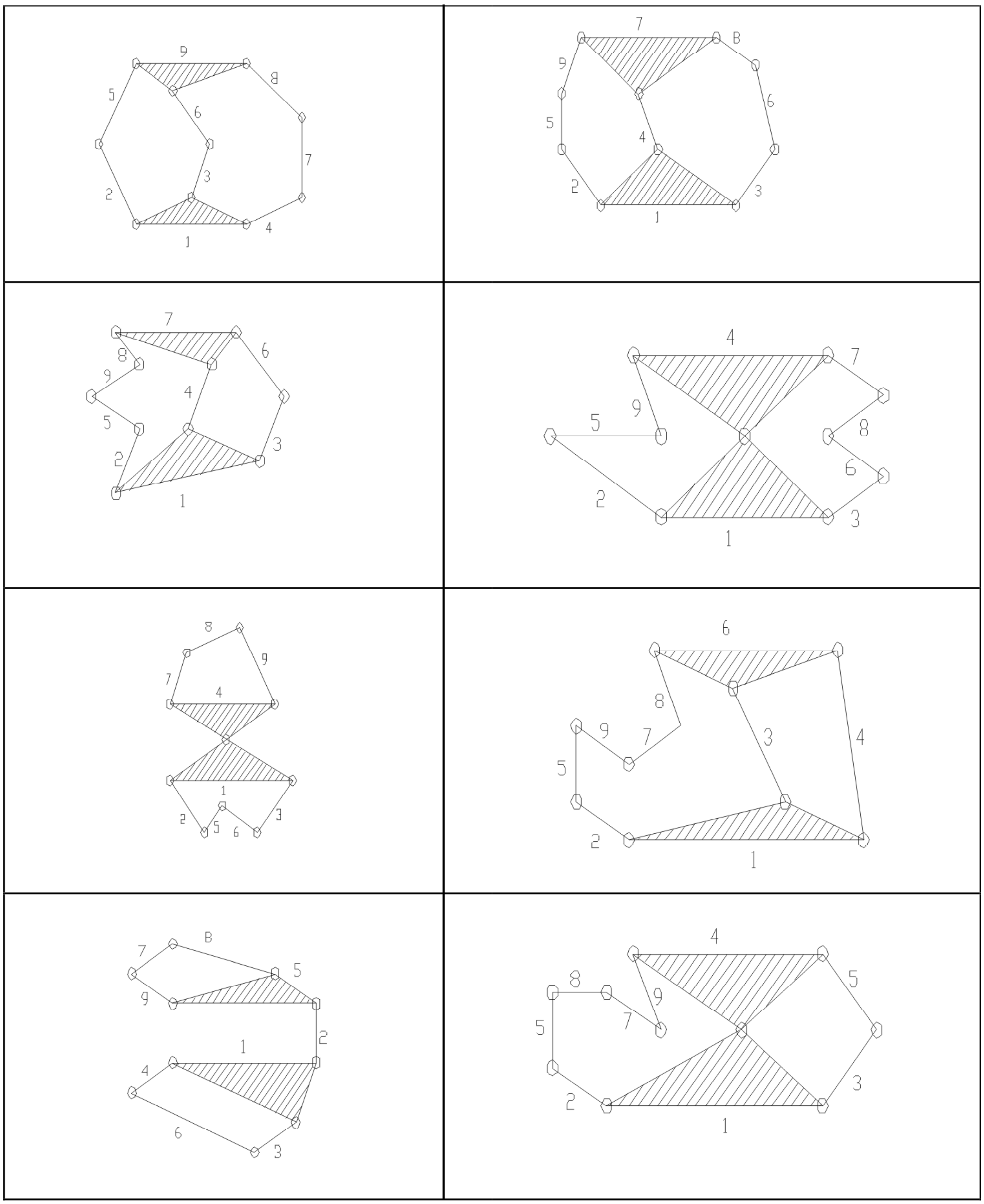
NUMBER OF LINKS (N) = 9 ;DEGREE OF FREEDOM (DF) = 2

N2 = 7; N3 = 2; N4 = 0; N5 = 0; N6 = 0

Output of the program : Shown in Table 3.

**TOTAL NO. OF VALID CHAINS ENUMERATED = 2**

**Table 3**
**Output for the assortment of : 9_4_7-2-0-0**



The table 4. gives the program output as well as compares with results already established by the researchers for the number of chains generated for given combination of N and dof.

**Table 4**
**Comparison of results**

| *Sl.No* | *Number of Links(N)* | *Deg.of Freedom (dof)* | *Number of Chains generated using proposed algorithm[13]* | | *Results Reported by Hwang and Hwang [5]* |
|---|---|---|---|---|---|
| 1 | 9 | 4 | 2<br>8 | 10 | 10 |

## V. DISCUSSION

For innovative design and development of products, a necessary prerequisite for a designer is to explore as many diverse design options as possible at the conceptual design stage of product development. It is at this stage that techniques and results of structural synthesis of mechanisms can serve as valuable aids to the designer in his search for novel concepts for mechanism-related products.For the given combination of the binary, ternary and the quaternary links the number of chains generated are indicated in the Table 6 it is found that the number of distinct kinematic chains generated or enumerated for the 9 – link two degree of freedom are 10 in all. The results compare well with the established results obtained by the researcher Hwang and Hwang [5]. The advantage of the application of the current method is that it uses coding algorithm which is the step towards digitalization of kinematic chains for the ease of storage and retrieval of the same and can be easily catalogued.

## VI. CONCLUSION

The paper illustrates the approach, based on Maxcode algorithm, to enumerate or generate the distinct kinematic chains for any selected assortment. The computer program therefore user interactive. Max code has been widely accepted by graph theorists as a complete graph invariant and has been used in the current work for differentiating co-spectral, non-isomorphic chains. The results in the output tables (2,3) demonstrates an effective approach aiming at digital storage of generated chains for the ease of cataloguing.

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