

COMPUTER AIDED ANALYSIS AND SELECTION OF OPTIMAL STRUCTURAL DIAGRAM FOR 3 STAGE GEARBOX OF LATHE HEADSTOCK

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Abstract- A gearbox is a mechanical device that is used to provide speed and torque conversions from a rotating power source to output shaft. A gearbox is formed by mounting different gears in appropriate speed ratios to obtain the desired variations in speed. Gearboxes usually have multiple sets of gears that are placed appropriately to obtain different speed reduction. The process of gear design is an extremely vast and critical area, and whole research coverage in such work is not possible. To design a complete gearbox it is necessary to find the optimal structural diagram. This diagram helps the designer to design the gearbox accurately. In case of 3 stage gearbox design, lots of combinations of structural diagrams are obtained and out of these diagrams it is time consuming to find manually the optimal structural diagram. In this paper a new methodology is suggested by developing a computer program in “C” to evaluate and analysis the structural diagrams and it helps to find the optimal structural diagram within very short duration of time. This computational approach definitely helps the designer to obtain the best structural diagram within short time duration.

Keywords- Structural Diagram, 3 Stage Gearbox, Transmission Ratio Restriction Criterion And Minimum Shaft Size Criterion.

I. INTRODUCTION AND LITERATURE REVIEW

For transmission of power, gearbox have been used since the dawn of civilization. Gearbox can be engineered to allow gear ratio changes to enable output shaft speed while keeping the input speed and torque at the same value. The primary advantage for using a gear box for changing speed is to enable the full power to be transmitted at the different speeds.

The location of speed boxes i.e. gearboxes which are employed in machine tools are in main drive and its principles of designing are dealt with stepped regulation of speed only in certain discrete values of the spindle rpm. To design a speed box for machine tool drives, it is important to find out the best possible structural formula for developing ray diagram to find out the best transmission ratio and speeds on the different shafts of the gearbox. Structural diagram is the graphical tool which is used to find out the range ratio of transmission groups. These structural diagrams are drawn from the structural formulae. The structural diagrams gives information about the number of shafts in the gearbox, the number of gears on each shaft, the order of changing transmission in individual groups to get the desired spindle speed, and, the transmission range and characteristics of each group. Various researchers had worked in the areas of optimized design of spur gear reduction unit by incorporating ray diagrams but not much work has

been done on development of computer programs to find the best structural diagrams. The aim of the present study is to develop a “C” program to find out the best suitable structural formula for the design of a 3 stage gearbox. It will not only reduce the calculation time but also eliminate the human errors. Literature survey clears that there is a great lack in the published material about the design of multi-speed machine tool gearboxes [1-11]. For roughing operations this is often measured by the rate of metal removal and during batch production by the quantity of work pieces which can be machined in a minimum time between regrinds [3][4][6]. Concept from optimization and decision theory can play an important role in all steps of design stages. Gearboxes present a very important group of machine members. They are utilized in a great number of engineering fields. They which must satisfy very rigorous technical requirements regarding reliability, efficiency, precise manufacturing of products, bearing, etc. The structural diagram can be achieved according to the structural formulae. It gives information about the number of shafts and the number of gears on each shaft. By analyzing the gearbox speed number to its coefficients i.e. the transmission stages, the characteristics of each stage and the number of transmission ratio in each stage can be calculated [1] & [4]. Researchers develop methods by which design of gearboxes driven by double speed electric motors achieves the required number of speeds with small number of rotating

elements, smaller dimensions and higher overall efficiency at the least deviation between theoretical and actual speeds. The increase of utilization factor values is significant when using gearboxes driven by double speed motors [12]. Researchers also put forwarded some optimized design of the gearbox for compact machine tools [13].

II. STRUCTURAL DIAGRAM

It is a graphical tool which is used to find the range ratio of transmission groups. These structural diagrams are drawn from the structural formulas. So the structural diagrams give information about: The number of shafts in the gear box, the number of gears on each shaft, the order of changing transmissions in individual groups to get the desired spindle speed and the transmission range and characteristics of each group.

Suppose a speed on one shaft yields two speed values on the next shaft. The no. of speed steps of the particular transmission group is p=2. If the transmission is through gears, the transmission ratios that provide the two new speed values must lie in the following range:

$$n1/nz = i_{max} = 2 \text{ (maximum increase in speed)}$$

$$n2/nz = i_{min} = 1/4 \text{ (max reduction in speed)}$$

Transmission range for any stage:

$$i_g = i_{max} / i_{min} = 8$$

For any stage: if there are Z 1 steps:

$$n1/n2 = n2/n3 = \dots = n_{z-1}/n_z = K$$

Since speeds are to be in GP, $K = \phi^x$.

X characteristics of the transmission stage

$$Z = P1 * P2 * \dots * P_u$$

$$Z = P1(x1) * P2(x2) * \dots * P_u(x_u) \dots \text{ Structural Formula}$$

P1 speed steps in stage. x1 characteristic of stage.

Where $X1=1, X2=P1, X3=P1 * P2, \dots$
 $X_u = P1 * P2 * \dots * P_{u-1}$.

III. PROBLEM FORMULATION

3.1 Governing formula used in the study

The number of ways of arrangement is evaluated from number of speed steps “Z”.

$$\text{Value of } \phi = \left(\frac{z-1}{z} \sqrt{\frac{n_z}{n_1}} \right)$$

ϕ is the geometric progression ratio
 n_z = maximum value of rpm
 n_1 = minimum value of rpm
 z = number of speed

Finding RPM of the speed box from geometric progression

$$n_1 = \text{minimum value of rpm}$$

$$n_2 = n_1 \times \phi$$

$$n_3 = n_2 \times \phi$$

...

...

$$n_z = (n_{z-1}) \times \phi$$

Structural formulae:

$$Z = p1(x1) p2(x2) p3(x3)$$

$$Z = p1(x1) p2(x3) p3(x2)$$

$$Z = p1(x2) p2(x1) p3(x3)$$

$$Z = p1(x3) p2(x1) p3(x2)$$

$$Z = p1(x2) p2(x3) p3(x1)$$

$$Z = p1(x3) p2(x2) p3(x1)$$

Here, P₁, P₂, P₃ = transmission group and X₁, X₂, X₃ = characteristics of each transmission group respectively.

Transmission ratio restriction $i_g \leq i_{max} / i_{min} = 2 / (1/4) = 8$ & $i_m = \phi^{(p_m-1)X_m}$

Between shaft I & II

$$m=1, i_g = i_{max} / i_{min} = \phi^{(p1-1)X1}$$

Between shaft II & III

$$m=2, i_g = i_{max} / i_{min} = \phi^{(p2-1)X2}$$

Between shaft III & IV

$$m=3, i_g = i_{max} / i_{min} = \phi^{(p3-1)X3}$$

3.2 Selection criteria of the arrangements

There are basically three criterions. They are as follows:

- Transmission ratio restriction criterion
- Minimum shaft size criterion
- Checking of characteristics for each transmission group respectively for each accepted arrangement of structural diagrams. Here the narrow characteristics are accepted.

Transmission ratio restriction ($i_g \leq 8$): The transmission range of group = $i_g = i_{max} / i_{min} = 2 / (1/4) = 8$, where $i_{max} = 2$ & $i_{min} = 1/4$

Minimum tot shaft size ($\sum d = \min$):

$x1 \leq x2 \leq x3 \leq \dots \leq x_{u-1} \leq x_u$. The best version which ensures that it will be one in which the n min values of the intermediate shafts are maximum and n max values of the intermediate shafts re minimum.

3.3 Design of case study

In this paper a simple but very troublesome problem is taken as case study. The inputted values are taken as follows:

$$Z = 12$$

$$n_z = \text{maximum value of rpm} = 1000$$

$$n_1 = \text{minimum value of rpm} = 80$$

Here bilateral type of distribution is adopted.

3.4 Guidelines for selecting factors of “Z”

Selection of most suitable layout or factors of “Z” is determined by economy, simplicity of design and the

optimum gear ratio and size. The factors of “Z” value for 3 stage gearbox design are taken in such a way that:

- It should be in multiple of prime numbers. Basically it is taken as multiple of 2 or 3 or 2 and 3. Preference is given to those factors where 2 or 3 or combination of 2 and 3 is present.
- If step “a” is not possible then the next economical combination is accepted.
- In some cases, for same “Z” value, there may be better combination of factors in 4 stage than in 3 stage. In this situation the user should go for the best economical combination of factors.
- Lastly, the value and factors of “Z” should be taken such a way that it is practically feasible for 3 stage gearbox design w.r.t its rpm.

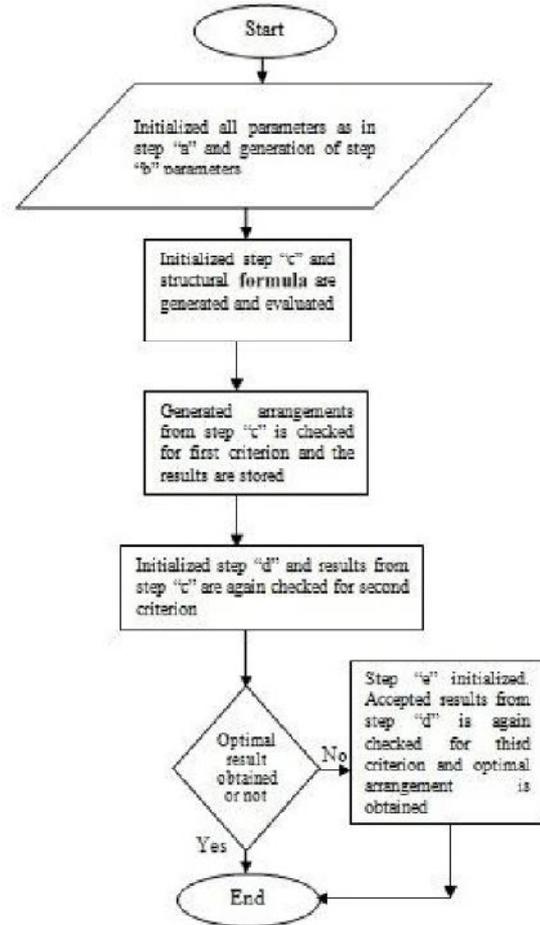
IV. DETAILS OF THE PROPOSED PROGRAM

4.1 Algorithm of the program

The program for evaluating and analysis of structural diagrams for various combinations is very user friendly. The algorithm for the proposed program is as follows:

- The data are inputted first, i.e. value of “Z”, “ N_{min} ”, “ N_{max} ” and possible factors of “Z”. Where, Z = No. of speed steps. Here the user must know the practical feasibility of the inputted values. Whether the inputted values are practically possible or not for 3 stage gear box, it should be known to user.
- For each speed steps the speeds are generated and Progression Ratio ϕ is calculated. Here ϕ and range ratio are not presumed. It is calculated by the program.
- For each possible factor combination the structural arrangements are evaluated and checked for transmission ratio restriction criterion. If a particular arrangement is accepted then it is stored.
- All the stored arrangements are checked for minimum shaft size criterion and accepted arrangements are again stored. In this step sometimes only one arrangement is accepted out of the all structural arrangements. Then the program declares the selected arrangement as the optimal one.
- If there are two or more arrangements are accepted in step “d” then the program move to the third screening i.e. checking of characteristics for each transmission group respectively for each accepted arrangement of structural diagrams. Here the narrow characteristics are accepted.
- Hence, the best optimal structural arrangement is obtained.

4.2 Flow chart of the proposed program



V. RESULTS AND DISCUSSION

5.1 Computational results

Enter the value of $z = 12$
 Enter the value of initial speed in rpm = 80
 Enter the value of final speed in rpm = 1000
 The value of $\phi = 1.258111$
 Computational time = 4.5632 seconds
 The value of speed for 12 steps are
 $n[1]=80.000000$
 $n[2]=100.648911$
 $n[3]=126.627541$
 $n[4]=159.311554$
 $n[5]=200.431671$
 $n[6]=252.165359$
 $n[7]=317.252106$
 $n[8]=399.138489$
 $n[9]=502.160675$
 $n[10]=631.774048$
 $n[11]=794.842102$
 $n[12]=999.999878$

Enter the factors: 2, 2, 3
 The factors have 3 different combinations:
 2 2 3
 2 3 2
 3 2 2
 For 2 2 3 combination six structural formulac are obtained:

$$z=2(1)2(2)3(4)$$

Let's check its acceptability...

Imax/Imin are

1.258111

1.582844

6.277008

This arrangement is accepted by "a" and "b" criteria and this arrangement can be checked by criterion "c" for finding optimum arrangement.

$$Z=2(1)2(6)3(2)$$

Let's check its acceptability...

Imax/Imin are

1.258111

3.965651

2.505396

This arrangement is accepted by criterion "a"

$$z=2(2)2(1)3(4)$$

Let's check its acceptability...

Imax/Imin are

1.582844

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Let's check its acceptability...

Imax/Imin are

3.965651

1.258111

2.505396

This arrangement is accepted by criterion "a"

$$z=2(3)2(6)3(1)$$

Let's check its acceptability...

Imax/Imin are

1.991394

3.965651

1.582844

This arrangement is accepted by criterion "a"

$$z=2(6)2(3)3(1)$$

Let's check its acceptability...

Imax/Imin are

3.965651

1.991394

1.582844

This arrangement is accepted by criterion "a"

For 2 3 2 combination

Another six structural formulae are obtained:

$$z=2(1)3(2)2(6)$$

Let's check its acceptability...

Imax/Imin are

1.258111

2.505396

3.965651

This arrangement is accepted by "a" and "b" criteria and this arrangement can be checked by criterion "c" for finding optimum arrangement.

$$Z=2(1)3(4)2(2)$$

Let's check its acceptability...

Imax/Imin are

1.258111

6.277008

1.582844

This arrangement is accepted by criterion "a"

$$z=2(3)3(1)2(6)$$

Let's check its acceptability...

Imax/Imin are

1.991394

1.582844

3.965651

This arrangement is accepted by criterion "a"

$$z=2(6)3(1)2(3)$$

Let's check its acceptability...

Imax/Imin are

3.965651

1.582844

1.991394

This arrangement is accepted by criterion "a"

$$z=2(2)3(4)2(1)$$

Let's check its acceptability...

Imax/Imin are

1.582844

6.277008

1.258111

This arrangement is accepted by criterion "a"

$$z=2(6)3(2)2(1)$$

Let's check its acceptability...
 I_{max}/I_{min} are
 3.965651
 2.505396
 1.258111
 This arrangement is accepted by criterion "a"
 For 3 2 2 combination
 Again six structural formulae are obtained:

$z=3(1)2(3)2(6)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 1.582844
 1.991394
 3.965651
 This arrangement is accepted by "a" and "b"
 criteria and this arrangement can be checked by
 criterion "c" for finding optimum arrangement.

$Z=3(1)2(6)2(3)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 1.582844
 3.965651
 1.991394
 This arrangement is accepted by criterion "a"

$z=3(2)2(1)2(6)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 2.505396
 1.258111
 3.965651
 This arrangement is accepted by criterion "a"

$z=3(4)2(1)2(2)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 6.277008
 1.258111
 1.582844
 This arrangement is accepted by criterion "a"

$z=3(2)2(6)2(1)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 2.505396
 3.965651
 1.258111
 This arrangement is accepted by criterion "a"

$z=3(4)2(2)2(1)$
 Let's check its acceptability...
 I_{max}/I_{min} are
 6.277008
 1.582844
 1.258111
 This arrangement is accepted by criterion "a"

The best selected optimum arrangements are

- 2(1)2(2)3(4)
- 2(1)3(2)2(6)
- 3(1)2(3)2(6)

From these arrangements using criterion "c"
 2(1)2(2)3(4) is the best optimal arrangement.

5.2 Manual results

Table I. Detail findings of the case study manually

For "Z" = 12 Factors: 2 2 3 Possible combination	Structural formulae	Accepted by criterion "a"	Accepted by criterion "b"	Accepted by criterion "c"
2×2×3	2(1)2(2)3(4), 2(1)2(6)3(2), 2(2)2(1)3(4), 2(6)2(1)3(2), 2(3)2(6)3(1), 2(6)2(3)3(1)	2(1)2(2)3(4), 2(1)2(6)3(2), 2(2)2(1)3(4), 2(6)2(1)3(2), 2(3)2(6)3(1), 2(6)2(3)3(1)	2(1)2(2)3(4)	2(1)2(2)3(4)
2×3×2	2(1)3(2)2(6), 2(1)3(4)2(2), 2(3)3(1)2(6), 2(6)3(1)2(6), 2(2)3(4)2(1), 2(6)3(2)2(1)	2(1)3(2)2(6), 2(1)3(4)2(2), 2(3)3(1)2(6), 2(6)3(1)2(6), 2(2)3(4)2(1), 2(6)3(2)2(1)	2(1)3(2)2(6)	
3×2×2	3(1)2(3)2(6), 3(1)2(6)2(3), 3(2)2(1)2(6), 3(4)2(1)2(2), 3(2)2(6)2(1), 3(4)2(2)2(1)	3(1)2(3)2(6), 3(1)2(6)2(3), 3(2)2(1)2(6), 3(4)2(1)2(2), 3(2)2(6)2(1), 3(4)2(2)2(1)	3(1)2(3)2(6)	

5.3 Structural diagrams of the three selected optimal arrangements

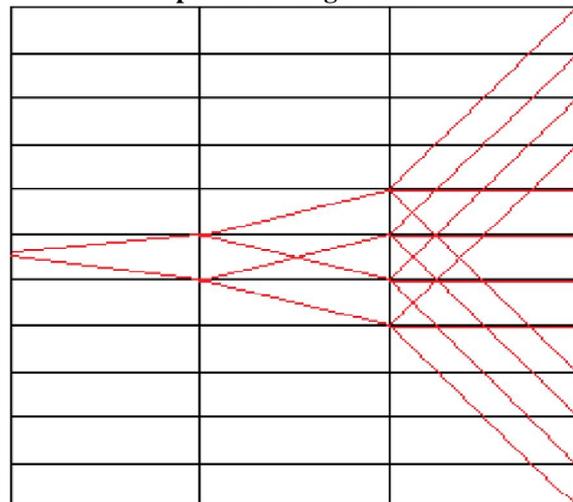


Fig. I. Structural diagram for arrangement 2(1)2(2)3(4)

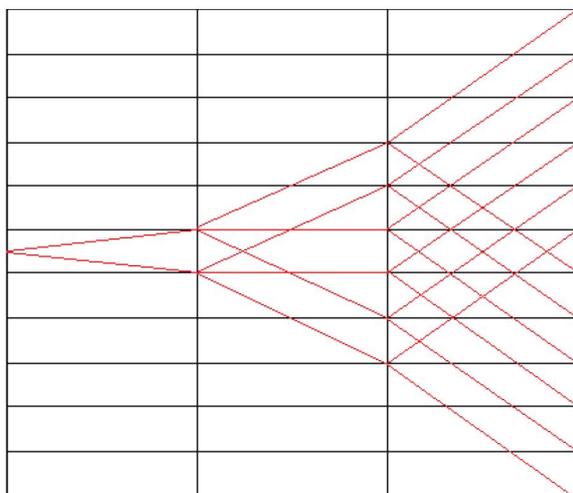


Fig. II Structural diagram for arrangement 2(1)3(2)2(6)

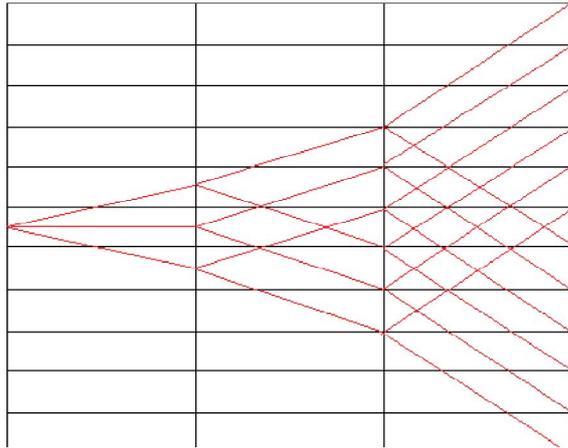


Fig.III Structural diagram for arrangement 3(1)2(3)2(6)

Hence, it is clear from the results and structural diagram that the best optimal arrangement is 2(1)2(2)3(4). The results obtained from computational approach and manual calculations are same and the structural diagram validates the statement. Thus this program is used to find the best optimal arrangement in less than 5 seconds without any error.

CONCLUSION

This solution can be carried out to find out the optimized arrangement of structural diagram for the design of the gearbox in less than 5 seconds. Also the stepwise solution of this present work would be helpful to a design engineer in reducing complexity for design a Gear box. In this paper a totally new approach of finding best optimal arrangement of structural diagram is suggested. This computational approach definitely helps the design engineer to take optimal decision without any error.

★★★

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