APPLICATIONS OF PANTOGRAPH

[Paritosh Rustogi]

Abstract— **is paper intends to give proposal and reasoning for various applications where a pantograph mechanism can be utilized to obtain a simpler machine with high accuracy. A pantograph is an old mechanism and is widely used in electrical locomotives to transfer electricity from catenary lines. It consist of 5 linkages forming parallelogram, each of the link is connected with the help of pin joint in order to form a revolute pair. Its only function is to imitate an enhanced or dwindle image of the geometry it traces. By this virtue, it can be installed with some modifications in various machines to ease the complexity of these machines and their costs. Individual modelling and motion analysis in solidworks of these mechanism is also in the scope of this paper, but due to redundancy of same kind of results only some results are shown. Analysis is done by using three types of pantograph, so that all three same outputs can vouch for feasibility of application.**

Keywords— *pantograph.*

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INTRODUCTION:

The term 'PANTOGRAPH' [1] stands for a linkage constituting of five link connected with pin joints to form revolute pairs. A Pantograph is connected in a manner based on parallelograms so that the movement of one point, in tracing an image, produces identical movements by second point. It has an ability to scale and copy simultaneously the image it traces. Also, the fixed point, copying point and tracing point always comes in a straight line. These abilities constitutes many engineering applications of pantograph mechanism.

KINEMATIC LINK [2]

Each part of a machine, which moves relative to some other part, is known as a kinematic link (or simply link) or element. A link may consist of several parts, which are rigidly fastened together, so that they do not move relative to one another. A link or element need not to be a rigid body, but it must be a resistant body. A body is said to be a resistant body if it is capable of transmitting the required forces with negligible deformation .Thus a link should have the following two characteristics:

1. It should have relative motion.
2. It must be a resistant body.

Pantograph links must have these two qualities, otherwise links would deform and the input and output link will not able to attain their correct positions and the mechanisms will not be able to provide exact scaled shape.

KINEMATIC PAIR [2]

The two links or elements of a machine, when in contact with each other, are said to form a pair. If the relative motion between them is completely or successfully constrained (i.e. in a definite direction), the pair is known as kinematic pair. The kinematic pairs according to the type of contact between the elements may be classified as:

(a) Lower pair: When the two elements of a pair have a surface contact when relative motion takes place and the surface of one element slides over the surface of the other, the pair formed is known as lower pair. It will be seen that sliding pairs, turning pairs and screw pairs form lower pairs.

(b) Higher pair: When the two elements of a pair have a line or point contact when relative motion takes place and the motion between the two elements is partly turning and partly sliding, then the pair is known as higher pair. A pair of friction discs, toothed gearing, belt and rope drives, ball and roller bearings and cam and follower is the examples of higher pairs.
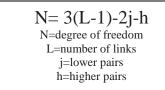
KINEMATIC CHAIN [2]

When the kinematic pairs are coupled in such a way that the last link is joined to the first link to transmit definite motion, it is called a kinematic chain. First link is a stationary base or the ground, with which second link is connected with the help of revolute pair. First link is also connected with the last link with the help of either a higher pair or a lower pair according to the requirement of degree of freedom. Higher pair will give 'two' as degree of freedom and lower pair will give 'one' as degree of freedom.

DEGREE OF FREEDOM [2]

In the design or analysis of a mechanism, one of the most important concern is the number of degrees of freedom (also called movability) of the mechanism. It is defined as the number of input parameters (usually pair variables) which must be independently controlled in order to bring the mechanism into a useful engineering purpose. It is possible to determine the number of degrees of freedom of a mechanism directly from the number of links and the number and types of joints which it includes.

Equation (shown in the box) is called Kutzbach criterion for the degree of freedom of a mechanism having plane motion. Conventionally, pantograph has 2 degree of freedom, but if there is a need of 1 degree of freedom the higher pair connecting the first and the last link can be changed to a lower pair.

$$N= 3(L-1)-2j-h$$

N=degree of freedom
L=number of links
j=lower pairs
h=higher pairs

PANTOGRAPH [1]

Pantograph is a linkage constituting of five link connected with pin joints to form revolute pairs. It is connected in a manner based on parallelograms so that the movement of one point, in tracing an image, produces identical movements by second point. A pantograph is used to reproduce to an enlarged or a reduced scale and as exactly as possible the path described by a given point.

If a line drawing is traced by the first point, an identical, enlarged, or miniaturized copy will be drawn by a pen fixed to the other. One of the revolute pair is fixed into the base, so that we can move this mechanism with respect to fixed point. Because of their effectiveness at translating motion in a controlled fashion, pantographs have come to be used as a type of motion guide for objects large and small. The point which traces the profile can be in any form e.g. Simple pin having conical point, rod having a bearing mounted at its end. And the point which gives the output can be in forms like router, pen, drilling machine etc.
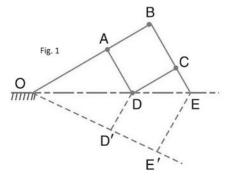

Fig. 1: Pantograph

It consists of a jointed parallelogram ABCD as shown in Fig. 1. It is made up of bars connected by turning pairs. The bars BA and BC are extended to O and E respectively, such that

OA/OB=AD/BE

Thus, for all relative positions of the bars, the triangles OAD and OBE are similar and the points O, D and E are in one straight line. It may be proved that point E traces out the same path as described by point D.

From similar triangles OAD and OBE, we find that

OD/OE=AD/BE

Let point O be fixed and the points D and E move to some new positions D′ and E′. Then

OD/OE=OD′/OE´

A little consideration will show that the straight line DD′ is parallel to the straight line EE′. Hence, if O is fixed to the frame of a machine by means of a turning pair and D is attached to a point in the machine which has rectilinear motion relative to the frame, then E will also trace out a straight line path. Similarly, if E is constrained to move in a straight line, then D will trace out a straight line parallel to the former.

Imp: One of the properties of pantograph is that Point **O** (fixed point), **D** (point having the output), **E** (the input point or the copier) lies in the straight line.

SCALE FACTOR

It refers to the magnification of the object. Scale factor can be found be knowing the distances from the fixed point to input point and to output point

The scale factor is given by

= Ratio of the distance from the fixed point to the output point (that is point **D** of Fig. 1) to the distance from the fixed point to the tracing point (That is point **E** of Fig. 1)

= length of OD/length of OE

The ratio will be constant weather we are moving the pantograph or not.

In figure 2, there are some proposed basic design that could be used. All these designs have quadrilaterals as parallelograms. Also XYZ lies in a straight line in every design. Though they provide excellent scale factor, but more the number of quadrilaterals more the chances of occurrence of deformation and error.
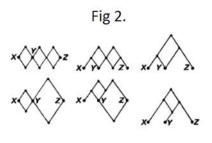

Fig. 2: Design of pantograph

APPLICATIONS:

Pantograph can be used for many applications in machining due to its ability to enhancing or dwindling the image it traces. Applications are:

1. Drafting and scaling a 2-D image on a plane.
2. Shaping and cutting the contour of a work piece of the desired profile.
3. Magnification or dwindling of displacement for signal conditioning.

4. Variable length testing gauges.
5. Force multiplier.
6. Elongation or compression of a workpiece.
7. Act as a lever.
8. Precise positioning.
9. Increase sensitivity of a system.
10. Transmission of electricity in trains.
11. Trolley Routes.

1. DRAFTING AND SCALING A 2-D IMAGE ON A PLANE [3]

Mostly, pantograph is for 2-D application because its fixed point can swivel about one axis only. By drafting, it means the pantograph traces the image by a conical point and simultaneously it draws up the scaled image by a pen which is attached to the different point of pantograph.
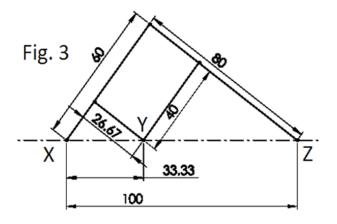

Fig. 3: Geometry of pantograph type1

For this application, analysis is done on a pantograph model (Fig. 3) in solidworks which has a scale factor of 1/3. In motion study, when point Z follows a circle of 30 cm in diameter then point Y draws a circle having 31.42 cm as its perimeter (Fig. 4).
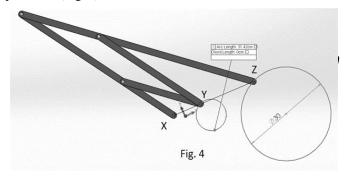

Fig. 4: 3-D model of pantograph type1

Fig. 5 represents the graph between displacements XY(Y axis) and XZ(X axis). Plot is a straight line, this shows that the there is a linear relation between the two. Therefore, both the displacements would occur at same constant rate simultaneously. So, whatsoever geometry point Z traces, exact scaled geometry will appear on point Y.
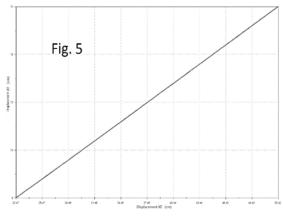

Fig. 5: Graph of relation between XZ(X axis) and XY(Y axis)

2. SHAPING AND CONTOUR CUTTING: [3]

It is done when there is a particular shape or profile of a workpiece is needed. It is very similar to drafting, the only difference being is it is done on 3-D objects. At point Z, the template is mounted whose profile it traces and at point Y, cutting tool is placed like milling machine, router and lathe etc. Motion study for this application is done on pantograph model shown in Fig. 3 and the results are same as shown in Fig. 4 & Fig. 5.

3. MAGNIFICATION OR DWINDLING OF DISPLACEMENT FOR SIGNAL CONDITIONING:
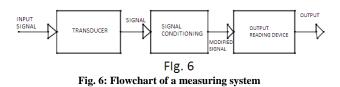

Fig. 6: Flowchart of a measuring system

Fig. 6 shows the stages in any measuring system [4]. After transducer stage, the signal needs some conditioning by magnify or shrink the transducer movement to make it readable in reading devices. Pantograph can work aptly as signal conditioning device. For magnification, transducer can be placed between X and Y of the pantograph and the output signal can be extracted by tracing the displacements of X and Z which is then transferred in output reading devices as shown in Fig. 7. As XY changes, XZ also changes with the same rate but in magnified form. For dwindle the signal, displacement XZ can act as input and displacement XY can act as output. These type of applications require highly accurate systems, therefore a linkage which magnify the displacements it

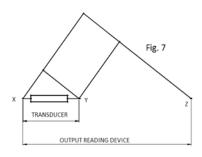encountered is aptly suitable. More the scale factor, more the magnification.

Fig. 7: Concept of application 3
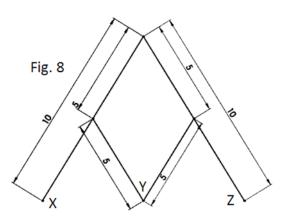
4. VARIABLE LENGTH TESTING GAUGES:

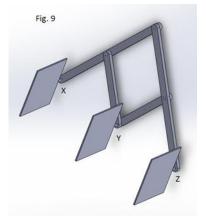**Fig. 8: Geometry of pantograph type2**

Fig. 9: 3-D model of pantograph type2

Length testing gauges [5] are used in almost every manufacturing industry. They are very essential for checking the efficacy of the whole manufacturing system. Pantograph can be used here with high efficiency. A pantograph model of 0.5 as scale factor with sheet metal plates hinged at its X, Y and Z points is required for this application as shown in Fig. 8 and 9. As X is the fixed point, workpiece having ideal length with which lengths of other machined workpieces are to be compared should be placed in between plates of X and Y. And the machined workpieces whom length are to be tested can be placed in plates of Y and Z. As length XY is equal to length YZ, the difference in the length of both the workpieces and the direction of the difference can be detected easily. Go/No-Go gauge can be easily made by pantograph by using two pantographs. One having the upper limit of length and the other having lower limit of the length. It is better than conventional gauges because there is no need of specially develop a gauge for a particular length. Its working length is variable and accurate.

5. FORCE MULTIPLIER:

Sometimes, there is a requirement of high force but if the system providing the force is not build to accumulate that much amount of force per time. At situations like this pantograph can the cheapest solution. Apply force F_1 in any arbitrary direction on point Z in pantograph shown in Fig.3 and 4. The direction of force will decide the trajectory of the straight line path followed by points Y and Z. Therefore these forces and displacements will always be collinear. Let this force F_1 moves point Z by distance D_1. And by the virtue of pantograph point y will move in the same direction by a distance of D_2 ($D_2=D_1/3$). Force exerted on point Y is F_2.

According to the law of conservation of energy, power input equals to the power output.
Power input=Power output
Work input/time=Work output/time
$$F_1.D_1=F_2.D_2$$
$$F_1*D_1*\cos\varphi_1=F_2*D_2*\cos\varphi_2$$
(φ_1 and φ_2 are angular displacements between forces and their respective displacements)
$$As, \varphi_1=\varphi_1=0$$
$$F_1*D_1=F_2*D_2$$
Therefore, $F_2=F_1*D_1/ D_2$
$$F_2=3*F_1$$
This concludes that, if there is no bending and deformation in the in kinematic links of the pantograph in Fig. 3 & 4, then force on point Y is thrice the force of point Z. More the scale factor, more the force emerges on point Y.

6. ELONGATION OR COMPRESSION OF A WORKPIECE:

If there is any need of a machine which is needed to do compression or expansion of very malleable or ductile materials, pantograph can be used very efficiently and cost effectively. For this application, pantograph shown in Fig. 10 and 11 can also be used. It has a scale factor of 0.25.Points X, Y' and Z' are fixed. Guiding walls are always required in such applications to stop any buckling of workpiece and to regulate the cross-section's geometry.
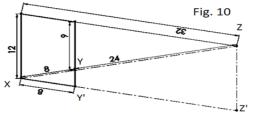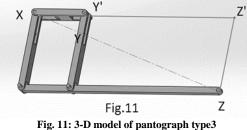
Fig. 10: Geometry of pantograph type3

In section 5, it's proved that force on point Y is a multiple of force on point Z. Therefore, workpiece should be placed in between X and Y to obtain more force. Also, triangles XYY' and XZZ' are similar. This means that if work piece is placed in between points Y and Y' by hinges and force is applied on point Z in the direction of ZZ' than same phenomenon will happen. YY' and ZZ' are parallel to each other. This gives variety of positions to choose for such an application.

Fig. 11: 3-D model of pantograph type3

7.   ACT AS A LEVER:

In Fig. 10 points X, Y and Z always remain in a straight line, therefore XYZ line can be taken as a rigid rod which is hinged at the point X. If a force can be applied at point Z only and point Z is given either clockwise rotation or anti-clockwise rotation with this force such that Length XYZ does not change, then this mechanism can act as a lever to lift the load on point Y.

If the input force requirement is more than supplied then first XYZ length can be increased by pulling it out in XZ direction, after this force is applied in in either clockwise rotation or anti-clockwise rotation such that Length XYZ does not change. This increment in XYZ length will reduce the input force required but this reduction is compensated by increment in distance travel by Z.

$$\text{Mechanical advantage of this lever is} = \frac{output\ force}{input\ force} = \frac{F_2}{F_1}$$

8.   PRECISE POSITIONING:

In machining like drilling, when the workpiece and the holes are very small and high precision and accuracy is needed for placing the drills on the points where drilling is to be done, in such conditions pantograph can help to precipitate the placement which can save working time of labors. Pantograph in Fig. 10 can be used. For this, a template depicting all the drill jobs of workpiece having a scale of 4 should be developed first. This template is placed nearby point Z and workpiece is placed nearby point Y. Point Y has drill machine

installed on it. Now, calibration of pantograph is to be done in which Y and Z points are placed on the same extremities of the workpiece and template simultaneously. By placing Z on the drill jobs on the template, drill machine on point Y got placed simultaneously on points where drill operations are to be performed.

9.   INCREASE SENSITIVITY OF A   SYSTEM:

Sensitivity [5] of a system is defined as how much output is there per unit input i.e. output/input. If there is a system whose output is in displacement then pantographs can be used to increase the sensitivity of the system. It is very important for a system have high sensitivity, otherwise system will not be susceptible to small changes in input. If a system is attached with pantograph at its output and its input is also in displacement then the compound sensitivity is:

$$\frac{Output}{Input * scale\ factor\ of\ pantograph}$$

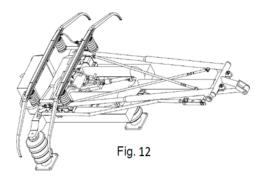## 10.   TRANSMISSION OF ELECTRICITY   IN   TRAINS:

Fig. 12: Pantograph on trains

A train pantograph is shown in Fig. 12. They are widely used in electric trains. They are used to transfer electricity from catenary lines [6] to electrical equipment of train. The pantograph is spring-loaded and pushes a contact shoe up against the underside of the contact wire of catenary to draw the electricity needed to run the train. The steel rails of the tracks act as the electrical return. It allows trains to attain higher speed.

11.   TROLLEY ROUTES:

Pantographs are also used as guide frames in heavy-duty applications including scissor lifts, material handling equipment, stage lifts and specialty hinges. All these applications have very low input displacement with respect to their ultimate change in length. These pantograph has more than one parallelogram attached to one another in series. First pantograph of Fig. 3 is a typical example for this kind of application.

CONCLUSION:

It may be a very old mechanisms, but it has not been obsoleted yet. Still in present days it has many beneficial uses. Pantograph is a parallelogram linkage which can be used for many applications with the help of some modifications. Pantograph can have more than one design and different applications require different designs. It is seen by motion analysis in solidworks that rate of change of displacements between points are constant which vouches for its feasibility in these situations. It is an accurate system which works with precision. It is highly efficient to work with and it also eases many painstaking operations. Its scope is very vast and it can also be used in some other applications which are not mentioned in this paper.

ASSUMPTIONS:

- There is no bending or deformation in the links of the pantograph whatsoever.

- Negligible power is consumed in the movements of pantograph linkages.

- No buckling of workpiece occurs in any case whatsoever.

- Its accuracy will always be maintained if there is no wear and tear of the arms of pantograph due to the movements of revolute pair of kinematic linkage.

FUTURE SCOPE OF RESEARCH:

Physical feasibility of some of these applications needs to be tested. It can also be installed with a CNC machine (In which all the movements are controlled by computer), which has tool on one point and a probe on other side. Finite Element Analysis (FEA) of pantograph in solidworks still needs to be performed of different designs to check which one has better viability in practical conditions.

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