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AN ADVANCED MANUFACTURING MACHINE, OCTAHEDRAL HEXAPOD MACHINING SYSTEM

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ABSTRACT

The quest for higher productivity and higher precision in the manufacturing industry calls for higher productive machines. In the field of advanced machine tools, enhanced performance is seldom achieved without greater design complexity, reduced operational flexibility, and higher cost. These drawbacks have installed innovation in India where most research and development efforts focus on incremental improvements to conventional machines. Hexapod actuator is used with octahedral frame called as space frame.

I. INTRODUCTION

The machine tool industry depends heavily on stacked axis computer-numerical-control(CNC) machines, which achieve a specified position and orientation of the spindle by controlling individually as many as six positioning axes (X,Y,Z, roll, pitch, and yaw). The CNC commands up to six separate movements, each performed independently, whose combined effects produce a target position. The manufacturing industry desired a more precise tool. The development of a high-precision, low cost machine tool became imperative for small companies ability to enhance the quality of manufactured products. Octahedral hexapod machine which promised superior accuracy, stiffness and speed as well as lower prices, simply assembly and greater accessibility. This was only possible because of power of computer, to control the simultaneous motions of six actuating struts.

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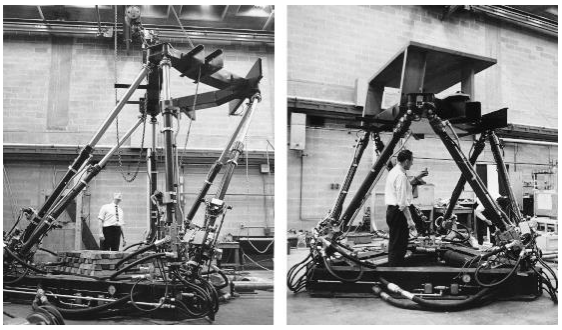
II. THE PRINCIPLE OF HEXAPOD STRUCTURES

Hexapod structures was creatively employs on stewart platform concept which is most commonly used for flight simulators. The hexapod actuators are almost similar to the stewart platform which is developed in the 1950's. The stewart platform is an equilateral triangle suspended in an octahedron frame by six actuators(strings). Two strings are attached at each corner of the vertices of the top triangle, down to the base of the octahedron frame and then fastened to the control devices. The control mechanism allows the operator to manipulate the platform through the 6DOF.

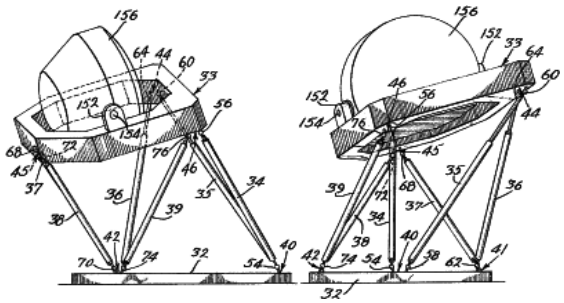


The hexapod mechanism is build inside of and attached to the upper three corner blocks (nodes) of the octahedron. Due to this arrangement the machining forces are guided towards the nodes. The hexapod actuators of octahedral hexapod machine consist of six extensible struts pivotally mounted at one end in pairs to face upper nodes of the octahedral frame. The struts are also connected pivotally to the other end to move the work platform i.e. machine spindle. The struts are actually the ball screw arrangement which can be raise, lower or tilt the platform in an infinite number of positions within the given range. In the hexapod the position of the spindle is adjusted by the lengthening

or shortening strut length, this is carried out by a control system, which is controlled by a computer using design software. The machine therefore, has no conventional X, Y, Z way members or axes for machine motion, just six extensible struts do the work with high precision.

III. WORKING OF OCTAHEDRAL HEXAPOD MACHINE

The hexapod actuator has a highly optimized kinematics system which provides six axis of freedom with very high rigidity to weight ratio. The octahedral hexapod machine do not have any conventional members like column slides, etc. by programming the rate of motion and length of each struts, the work platform can be move through a full axis of working zone.



The octahedral hexapod machine consists of six ball screw driven linear actuators attached, via ball and socket joints, at one end to a self-contained octahedral structure and at the other to a moving platform, which houses a spindle motor and cutting tool. Based on the concept of stewart platform, the upper ball joints that are attached to the octahedral structure are arranged so that the forces through strut pairs approximately intersect at the vertices of an equilateral triangle. The lower ball joints are equally spaced on the spindle platform.

Even move of the machine, even a simple single axis move, requires careful coordinated simultaneous move of all six struts. All the struts working together share the machining load. A computer coordinates movement of each strut. The controller is driven by G & M codes. The servo motors and spindle motors are controlled by a computer system that has the required speed selectively and often, concurrently, to execute a programmed tool path. The computer does all high speed calculations and sends them to a servo amplifier, which amplifies the signal and then sends it to the servo motors. The computer system incorporates motion control algorithms to generate six axis simultaneous output and to minimize errors due to servo lag, thermal errors and so on. The software enables the programmed path to be followed to an accuracy of 2 to 3 microns. The real time errors are mapped and stored in the files called personality files by the software. The personality files maps the different errors so that no complex on machine calibration is required. Feedback is given to the computer by encoders.

IV. CONSTRUCTIONAL FEATURES

Strut Assembly:
Struts are very important part of hexapod. The strut consists of a ball screw which is connected to the movable platform by a bifurcated ball and is then driven through the pivot point by Sphere Drive. A ball screw is used because of its low cost, reliability and its availability of the shelf. This assembly reduces inertia and critical speed problems. It has very high extension to contraction ratio due to the reason that the screw can pass through the unlimited space behind the pivot.

The pivot points are ball and socket joints(sphere drive and bifurcated ball). The ball and socket interference is coated with a special vibration damping lubricant. This result in smooth running of the system even in the shock loads.

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Sphere Drive:
The sphere drive is a special ball and socket. The advantage of ball and socket arrangement is its symmetry, loading, wear and temperature expansion are always concentric. Large surface coated with shear lubricant provide a good damping. Calibration is relatively easy. The ball is hollow from inside and accommodates a special brush less D.C. motor, a radial encoder and two ball nuts. The critical parts are properly protected from any damage and foreign material.

A ball screw strut passes straight through the centre of the sphere. The motor is located such that the driving forces are directed from the centre of the sphere. The socket is a narrow ring that contains a ball. To prevent the ball rotating as a reaction of a drive torque a simple restraining device in the socket protrudes into a groove in the sphere extending from one point to another.

Bifurcated Ball:
The word bifurcated means split or divided in to two parts. A pair of struts share a ball in a ball and socket joint to prevent them from rotating with respect to each other. The ball is made of two independent hemispheres jointed together. Each is connected to a hemisphere.

The centre of the ball is the datum point for determining the strut length. This is determined precisely by measuring the distance from the centre of the sphere drive to centre of the bifurcated ball. The socket is undersized and ball is retained in the undersized socket by magnetism. The extreme shock forces dislocate the joint without damaging any part of the structure.

Head Unit:
Several alternative head units can be attached to the hexapod actuator's platform. A arrangement is designed which provides power and communications to the head. The head unit is retained by a slip ring which is automatically locked and released at the head exchange station. The spindle can auto change quills and platform can auto change head units.

Spindle Motor:
The hexapod actuator with a variable speed spindle driven by a special D.C. motor. The motor is capable of delivering the power at high speeds of spindle (typically 4KW at 60,000rpm). Due to very high speeds of the spindle and motor air-cooled ceramic bearings are used. The entire head unit is air-cooled and the exhaust is spun into a vortex around the cutter to clear chips and to carry cutting fluid mist.

Automatic tool changing is carried out string the power of hexapod actuator to lock and unlock the quills holding the tools. Several quills are located at the tool exchange station. The motor is driven by a hybrid drive that responds to the signals from an encoder.

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V. IMPORTANT PROPERTIES OF OCTAHEDRAL HEXAPOD MACHINE:

Stiffness:

By just looking at the machine anybody will say that the machine is not so rigid. But as we take a closer look we will come to know that how rigid the machine is. Hexapod are inherently rigid due to their design geometry. The mechanisms make effective use of triangles, being the strongest geometric structure, i.e., a geodesic dome.

The machine uses an octahedron structure for the machine frame, which itself is characterized by high rigidity. The actuator forms a rigid truss five times the structural rigidity of a conventional machine. The hexapod uses six struts. Each strut applies force either push or pull on the frame in working. There are no beams present like conventional machine so all deflection in the actuator creates only direct axial stresses and the structural material are very rigid under axial loads.

For compression loads struts has a tendency to buckle, however the crucial buckling load is proportional to the 4^{th} power of strut diameter and inversely proportional to square of strut length. So struts of smaller diameter are used for more stiffness. Instead of bearing bending stresses hexapod only bears axial forces. The bending moment can be minimized by applying forces close to pivot joint and by resolving them to a common focal point.

One more unique feature of this machine is self enveloping means the cutting forces are internal in the structure and no force is needed to ground and so there is no need of special foundation. The stiffness is further increased by pre-loading ball screw and linkages. The typical design stiffness are of the order 35,000 kg/m.

Accuracy:
The stiffness of the machine also improves accuracy. The hexapod actuator uses sphere at there node point so their centres can be accurately defined. Each pair of strut focuses on the common point where forces are resolved without ending moments. As the hexapod structures are lighter in construction wear and tear between the parts is very less, there is much less backlash on axis reversal thereby promoting smoother movement profiles. Most errors in multi axis systems originate from the rotary or tilt stages but in hexapod it is easy to control the strut length while tilting. Also this machine has in built error aping features, so real-time errors can be reduce by suitable calibration.

Speed:
By reducing the mass of the moving parts, very fast accelerations can be achieved. Speeds up to 40 inches per second have to move workpiece as well as heavy bed in hexapod actuators carry only tool-head the work is mounted on the lower platform.

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Scalability:
These mechanisms are scalable in size, both upwards and downwards, to accommodate a multitude of applications, ranging from micro assembly and surgery, to six-degree-of-motion: milling, drilling, turning, welding, inspection, assembly, etc. There is no limit to the size of the hexapod.

Dexterity:
Dexterity means skill. This is very important point of hexapod. In hexapod design, the extension contraction ratio of strut and the articulation possible in the linkages. Dexterity accomplish by passing each struct through the centre of sphere housing a motor driving a roller screw. Wide angles of movements archived at tool platform with bifurcated ball joints, connecting pair of strut together using special magnetic sockets to retain the sphere to the tool platform. It provides 6 axis working volume of 1 cubic meter (35 cubic feet). Tilt pan of head is plus or minus 45°.

Cost:
Potentially, the cost is less than that of equivalent CNC machines. These devices are simply and easy to construct, providing a good ratio between machine size and actual workspace. Six identical members make for the construction of the system, providing ease of assembly, maintenance and lower inventory and labour costs. Calibration is facilitated by software

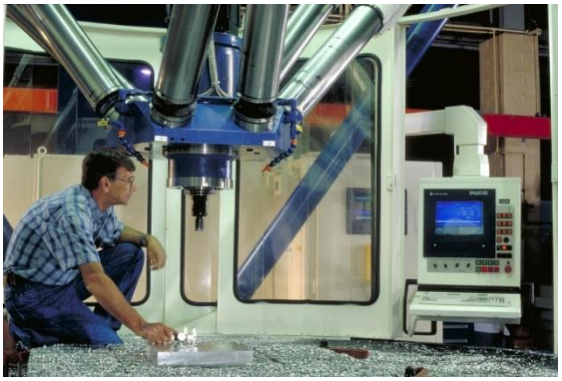
VI. CHARACTERISTICS OF LOADING OF HEXAPOD ACTUATORS

Machining forces are imposing on a work-piece primarily through bending strength in a conventional machine tool. Bending, however structurally inefficient mechanism where in substantial portion of the material are lowly stressed or even at near zero stress, hence essentially carrying no load.

A triangular load pattern, in contrast provides a truss effect, where all loads are axial and all material in every truss member is uniformly stressed. As a consequence, there is no inefficient material. For this reason, structures based on trusses always appear to the unpractised eye as delicate or inefficiently robust. The structures based on bending tend to look robust even though they are weaker and less rigid than an equivalent amount of material in truss configuration.

The hexapod machines can be so rigid, yet have such a spindly appearance because a force P resolves into $1/6^{th}$ P at each leg. With conventional machine structure, machine thrust is carried as large bending moments, which require an enormous of material to resist. This characteristic enables hexapods to be exceptionally stiff and rigid even being light weight thereby permitting higher speeds and accelerations.

VII. MERITS OF OCTAHEDRAL HEXAPOD MACHINE OVER CONVENTIONAL MACHINES



- Conventional machines consist of bed, base slides column, etc. and depend heavily on its supporting structure. The octahedral hexapod machine is independent of these constructions and has only a octahedral frame and six actuating struts.
- This structure is five times more rigid than conventional machines as all deflection in the actuators creates only direct axial tension or compression and structural materials are most rigid under axial loads.
- There are no conventional beams in a hexapod and hence no bending stresses are involved.
- The movements of these machines are much faster than conventional machines due to light in weight.
- In hexapod in-built personality files are incorporated which maps the error automatically.
- The unique feature of the hexapod structure against conventional machines is that, hexapod do not require a special foundation it can be place in locations inaccessible to the conventional machines like unstable floors ships etc.
- The hexapod gives higher stiffness and accuracy as compared with conventional machines. The accuracy is near about ±.01mm. Also it depends upon the software.
- Hexapod has simple modular construction which reduces maintenance. It also reduces the machine cost to 30% than equivalent conventional machine.
- Higher quality parts in lesser time.
- Reduces inspection due to higher accuracy.
- Fully automatic arrangement reduces downtime.
- Six-axis of freedom.
- Improve reliability and permits automatic mapping of errors and corrections of possible errors.
- Less wear and tear due to light in weight

VIII. CONCLUSION

This technology has the potential to substantially impact a wide range of manufacturing industries. It has provided a new plateau of functionality and precision from which the machine tool industry can continue to grow. It has the potential to do so at significantly lower cost and higher reliability. The octahedral hexapod machine is having yet have very huge market as we are still dependent on CNC and I am sure that this machine will change the old way of machining by a new machining.

REFERENCES

1. *U. Saranli, W. J. Schwind, and D. E. Koditschek, "Toward the Control of a Multi-Jointed, Monoped Runner," in Proceedings of the IEEE International Conference On Robotics and Automation, Leuven, Belgium, May 1998, vol. 3, pp. 2676–82.*
2. *H. Goldstein, Classical Mechnanics, Addison-Wesley, 1980*
3. *G. Gabrielli and T. H. von Karman, "What price speed?," Mechanical Engineering, vol. 72, no. 10, pp. 775–781, 1950.*
4. *Dasgupta B, Mruthyunjaya TS (2000) The Stewart platform manipulator: a review. Mech Mach Theory 35:15–40*
5. *Lin H, McInroy JE (2006) Disturbance attenuation in precise hexapod pointing using positive force feedback. Control Eng Prac 14:1377–1386*
6. *Ren G, Lu Q, Hu N, Nan R, Peng B (2004) On vibration control with Stewart parallel mechanism. Mechatronics 14:1–13*
7. *Dasgupta B, Mruthyunjaya TS (1998) Closed-form dynamic equations of the general Stewart platform through the Newton-Euler approach. Mech Mach Theory 33(7):993–1012*
8. *Lebret G, Liu K, Lewis FL (1993) Dynamic analysis and control of a Stewart platform manipulator. J Robot Syst 10(5):629–655*
9. *Harib K, Srinivasan K (2003) Kinematic and dynamic analysis of Stewart platform-based machine too structures. Robotica 21:541–554*

10. *Kim HS (1999) Design and control of Stewart platform based machine tool. PhD dissertation, Graduate School, Yonsei University, South Korea*
11. *Dohner JL, Kwan CM, Regerlbrugge ME (1996) Active chatter suppression in an octahedral hexapod milling machine: a design study. Proc SPIE 2721:316–325.*