Metrology
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Lecture – 41
Stage Position Metrology

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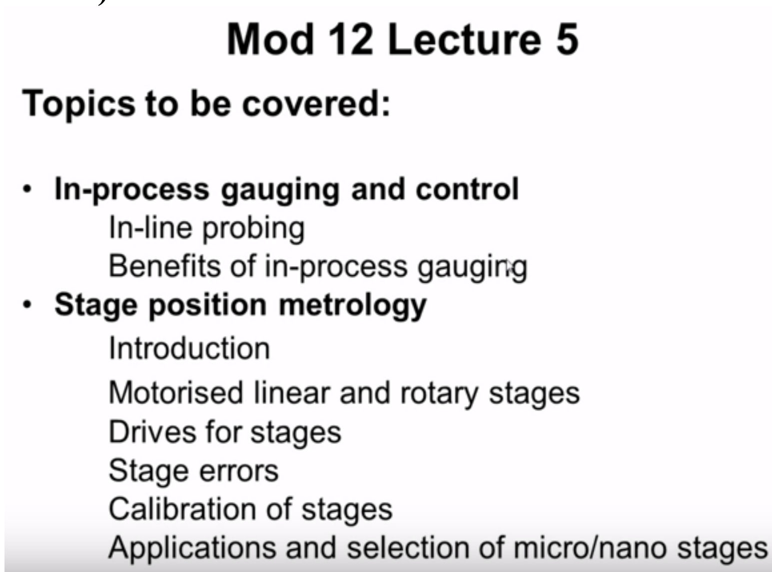

Let us start the module number 12, lecture number 5. In this lecture, we will continue the discussion on in-process gauging and control, so in this lecture, we will discuss about in-line probing and then we will move on to various benefits of in-process gauging and then we will move to the next topic that is stage position metrology in which we will be discussing about various precision staging of positions or table positioning systems.

So what are the various kinds of stages or tables available and what are the driving systems used in these tables and then what are the errors associated with these stages and then how we can calibrate the stages and finally, we will discuss about the various applications and how we can select the micro or nano stages. Now, let us discuss about in-line probing and then we will move on to the various benefits of in-process gauging.

And then we will move to the next topic that is stage position metrology in which we will be discussing about various precision staging or positions or table positioning systems, so what are the various kinds of stages or tables available and what are the driving systems used in these tables and then what are the errors associated with these stages and then how we can calibrate the stages and finally we will discuss about the various applications and we can select the micro or nano stages. Now, let us discuss about in-line probing.

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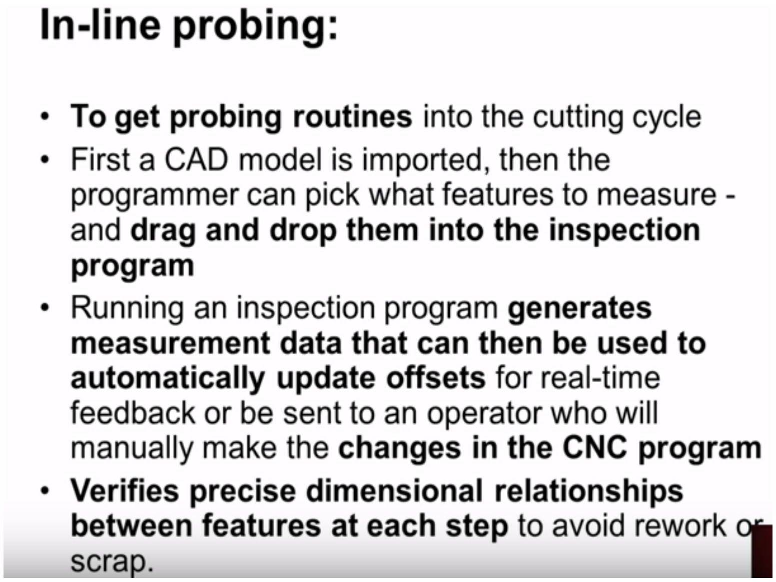

The main objective of in-line probing is to get probing routines into the cutting cycle, this is not exactly the gauging during the machining, so what we will do in between the different operations, we stop the machining and we bring the stylus into position to check whether a particular or not. If it is within the limit, then we allow the next operation to be continued, so we will just take a very simple example.

So we have work piece, so varying we have 2 operations, first operation is drilling operation, now that we had CAD out the drilling operation. Before the move to the next operation that is reaming operation, the first operation is drilling operation followed by reaming operation, so after completing the drilling operation, we removed the drill from this position and then we bring a probe, which is similar to CMM probe into this position, which will check whether the diameter of the hole is within the limits or not.

If the diameter is within the limits, then the next operation that is reaming operation is allowed, so in the in-line probing, what we have to do is, first the inspection program should be built into the main CNC program, for that we have to import the CAD model, then the programmer has to pick what are the various features to measure, the features like the diameter or the depth of the hole or the circle diameter like that, so the programmer will pick the various features.

And he will drag and drop them into the inspection program, then running an inspection program generates measurement data that then be used to automatically update offset that means the probe is brought into the position and the feature is checked. If the feature for example, the diameter is within the limits, then no change is made. If the diameter is not as per the specification, then the feedback is given to the CNC controller to make changes in the offset.

So that the work pieces can be produced to the specification, so this can be done automatically or the feedback is given to the operator, so that he will manually make changes in the CNC program. Verifies the precise dimensional relationships between features at each step of operation can be performed to avoid rework or scrap.

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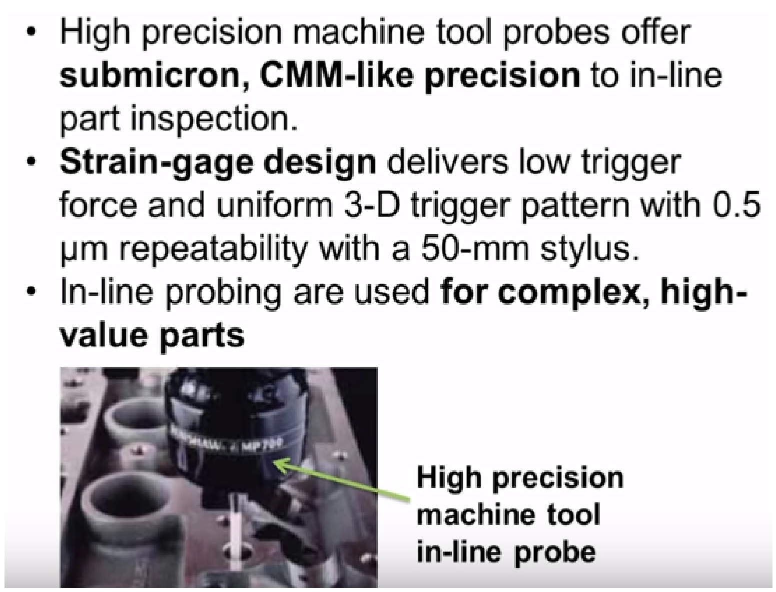

Now, high precision machine tool probes are available, which offer submicron or CMM-like precision to in-line part inspection. The strain gage based designs deliver low trigger force and uniform 3D trigger pattern with 0.5 micrometer repeatability with a 50 mm stylus. In-line probing are used for very complex and high value part, so that the precision is almost nullified. In this picture we can see a probe, which is inspecting the hole in IC engine body.

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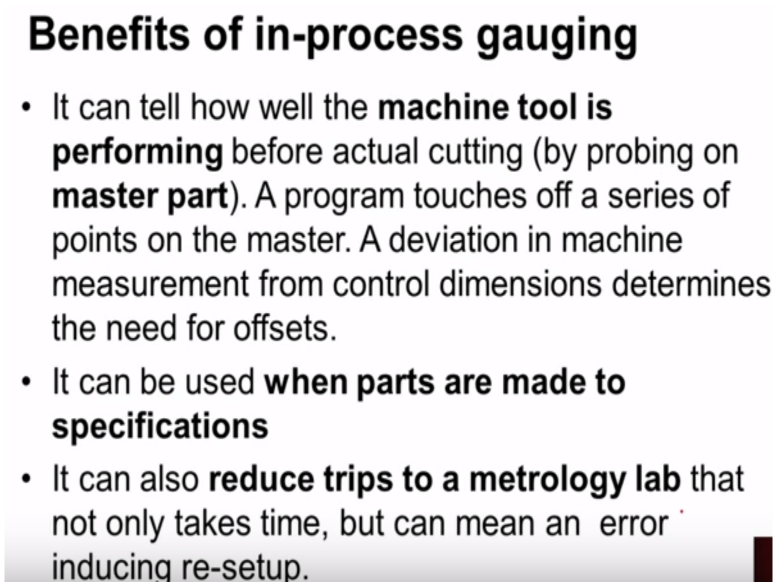

Now, let us move to the discussion on benefits of in-process gauging. The in-process gauging can tell how well the machine tool is performing before actually cutting the pieces that means we have to use the probing tool to probe the master part. A inspection program touches off a series of points on the master work piece. A deviation in machine measurement from the control dimensions determines the need for offset.

The in-line gauging can be used when parts are made to be made to the specifications. It can also reduce trips to a metrology lab that not only takes time, but can mean an error inducing re-setup.

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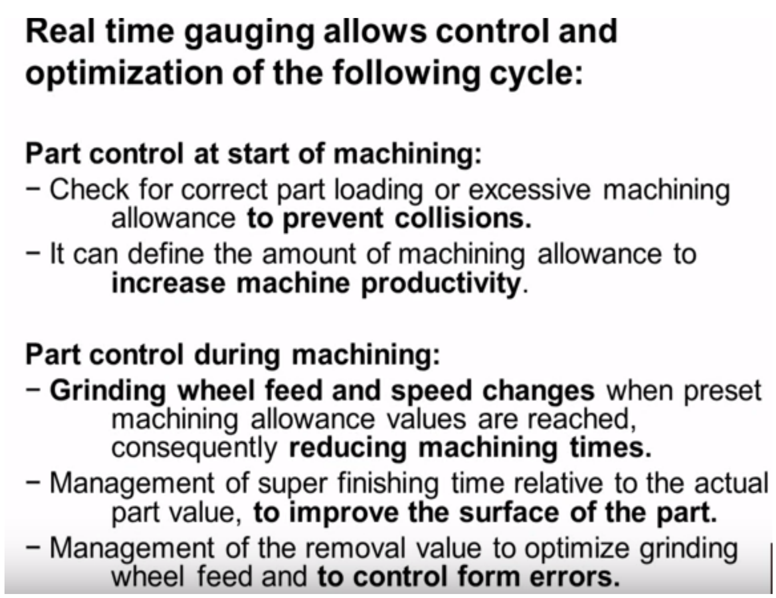

Now, there are benefits of real-time gauging, which allows control and optimization of the following cycle, part control at start of the machine that means check the pin process gauging checks for correct part loading or excessive machining allowance to prevent collisions of the probe. It can define the amount of machining allowance to increase machine productivity.

Part control during machining, grinding wheel feed and speed changes when preset machining allowance values are reached, consequently reducing the machining times and hence increasing the productivity. Management of super finishing time relative to the actual part value to improve the surface of the part, management of removal value to optimize grinding wheel speed and to control form errors, so proper form can be provided to the work piece by usage of in-process gauging systems.

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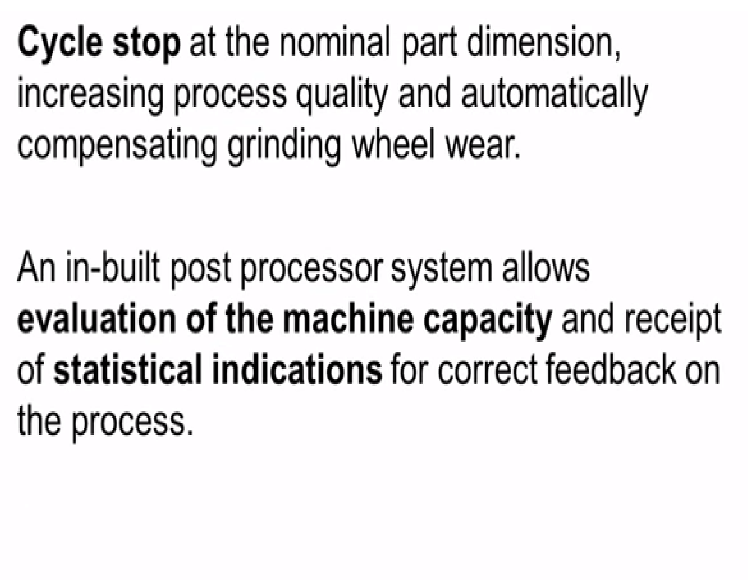

Then, cycle stop at the nominal part dimension, increasing process quality and automatically compensating grinding wheel wear. An in-built post processor system allows evaluation of the machine capacity and receipt of statistical indications for correct feedback on the process.

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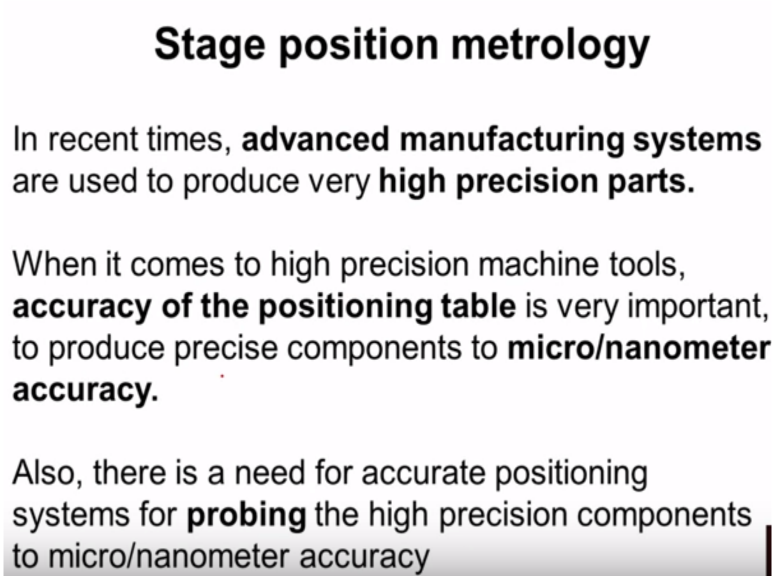

So, with this we will wind up the discussion on in-process gauging, now we will move to the next topic that is stage position metrology. In the recent times, advanced manufacturing systems are used to produce very high precision parts. When it comes to high precision machine tools, accuracy of the positioning table or positioning stages is very, very important, so that precise components can be produced to micrometer or nanometer accuracy.

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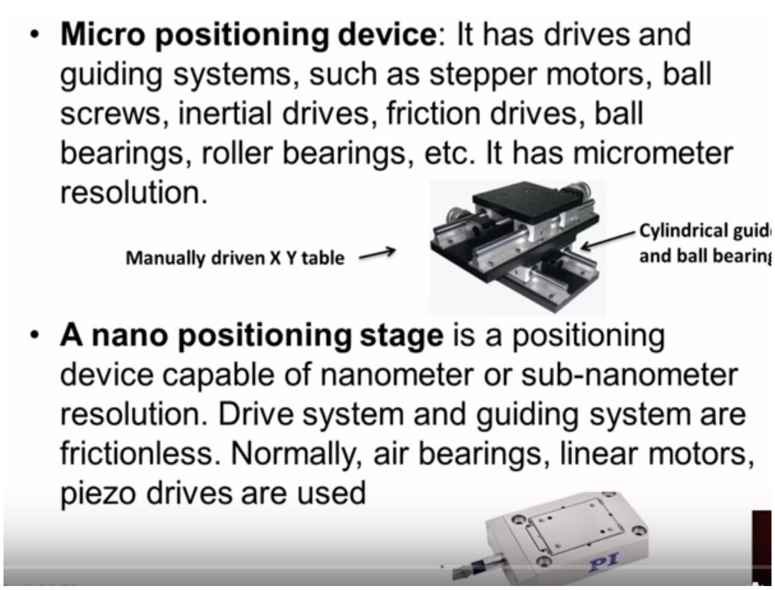

Also, there is a need for accurate positioning systems for probing high precision components to micrometer or nanometer accuracy. Now, what are micro positioning devices, they have drives and guiding systems such as stepper motors, ball screws, inertial drives, frictional drives, ball bearings, etc. these micro positioning devices have micrometer resolution like 0.1 micrometer resolution, 0.5 micrometer resolution, 1 micrometer resolution indicating up on the design and construction of the device.

In this diagram, we can see a micro positioning device, this is basically XY table, it has 2 movements in the X direction, as well as Y direction. We can see this is the table on which a work pieces can be mounted, we can directly place the work piece on the table or can use some suitable Fischer for mounting the work piece. We can see the wheels, 2 wheels for moving the XY table in the X direction, as well as Y direction.

We can also observe the cylindrical guide, we can see there is a guide here, there is another cylindrical guide and one more cylindrical guide and one more cylindrical guide here, so cylindrical guides and ball bearings also we can observe here, re-circulating ball bearings are used, so that it precisely moves to micrometer resolution. Now a nano positioning device, they are basically positioning devices capable of nanometer or sub-nanometer resolution.

Drive system and guiding systems are frictionless and normally, air bearings, linear motors, and piezo drives are used in nano positioning stages, so here we can see a nano commercially available nano positioning device, we have the table of the stage to keep the work piece, so this will move the nanometer resolution, so the range will be in terms of few micrometer like 0 to 50 micrometer, 0 to 100 micrometer ranges are available with nanometer or sub-nanometer resolutions.

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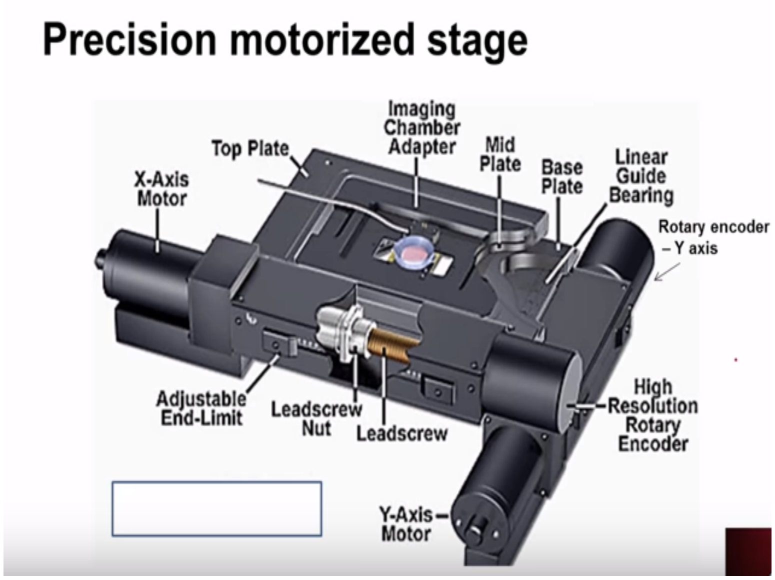

Now, this picture shows a motorized precision stage, we can observe this is X axis motor with X axis high resolution rotary encoder and we have Y axis motor with Y axis rotary encoder, where the motor is coupled to lead screw, we can observe the lead screw within that, so when the motor rotates the nut will move and hence the stage will move along with the work piece that is mounted.

We can also see adjustable end limits on both sides we have end limits and here also we can observe end limits for the Y axis, so encoders are provided for feedback purpose.

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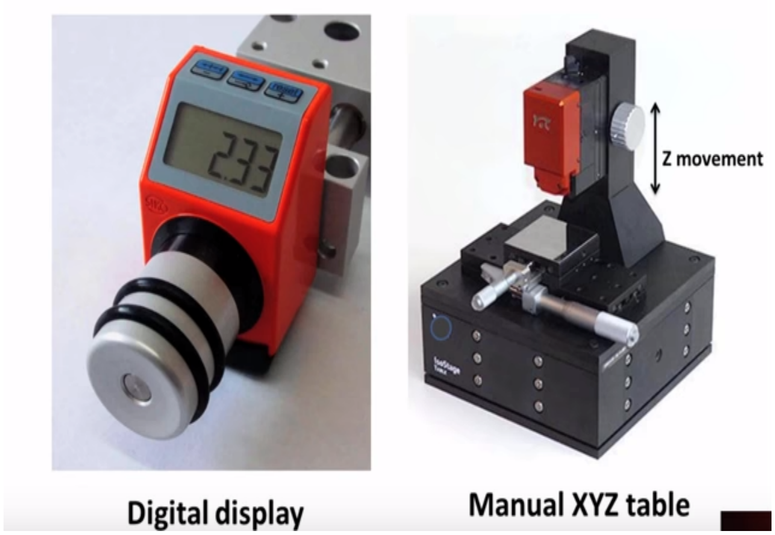

These pictures, we can see there is a digital display as the table moves, the digital display will indicate what are the amount of movement at any location, we can set the reading to 0 and from that position, when we move the table, what is the amount of table movement is indicated in this digital display. Now, here we can see a manual XYZ table, the Z movement, a vertical movement is by operating this knob and this is the table on which we have to keep the work pieces and then they can see the 2 micrometers are provided.

One for X and one for Y, so we can always take the reading, what is the movement of table can be read by reading the main scale at thimble of these micrometers and the accuracy, positioning accuracy in these cases will be like one micrometer, 2 micrometer depending up on the micrometer units what we use.

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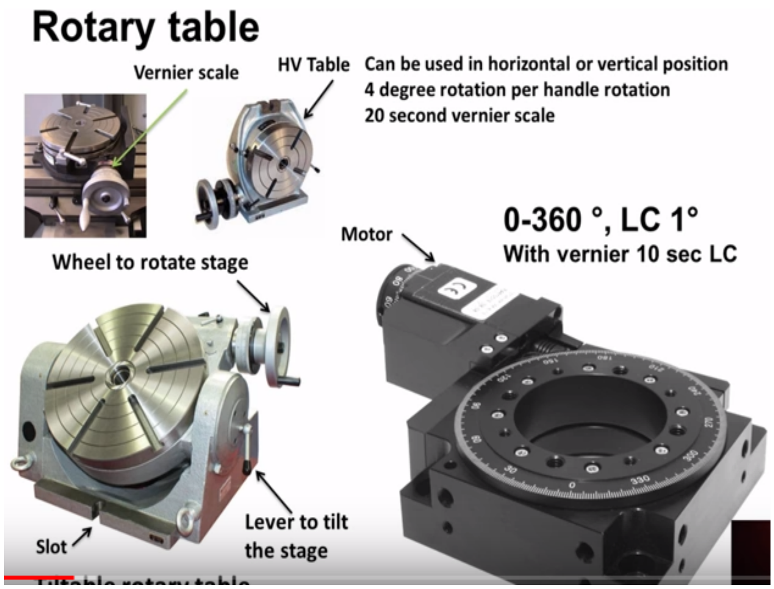

Now here we can see the rotary tables, manual rotary tables and motorized rotary tables, so we can see here this is the motorized rotary table, this is the motor fixed to the body of the table, so inside there will be mechanism to convert the rotary motion of the motor into the circular motion of the table, so this is 0, range is 0 to 360 degree and least count is 1 degree with vernier attachment, least count of 10 seconds or 5 seconds can be obtained.

You can see the holes are provided to mount the rotary tables on the machine tool tables, so here we can see another manually driven rotary table, this rotary table is mounted on the machine tool table by using tilt bolts. We can also see vernier is attached, so that very precise rotary position can be obtained, so this is called HV rotary table, H stands for horizontal and V stands for vertical and so these tables can be used in horizontal or vertical position.

Now we can observe that this is placed in the vertical position and we can tilt it and we can use it in the horizontal position also, this is wheel or to obtain the rotary motion of the table and we can see the scale and vernier, so the tables are available with 4 degree rotation per handle rotation and 20 second vernier scale. Using an vernier scale, an rotary accuracy of 20 seconds can be obtained and here we can see a tilt rotary table.

So this is the table on which we have to mount the work piece using the T bolt, we can see the T slots and this is the wheel to rotate the stage and we can tilt this table by operating this lever again, here we can see there is a vernier scale, so that very precise tilted position can be obtained.

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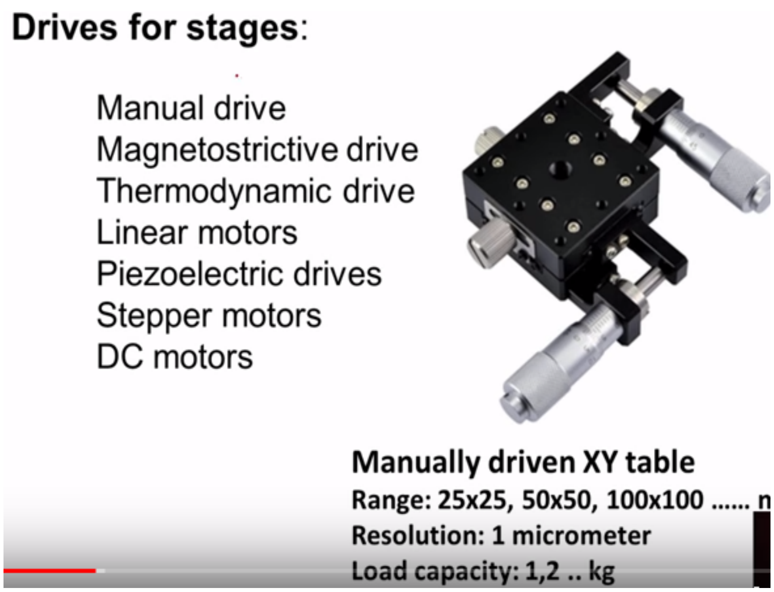

Now, what are the drives used for these stages, the stages can be manually driven stages or magnetostrictive drives can be used, thermodynamic drives can be used, linear motors can be used to move the stages or tables. Piezoelectric drives are also available for precise movement of micro nano movement of these tables, stepper motors also can be used, also DC motors are used to drive the stages.

In this picture, you can see manually driven XY table, you can see micrometers are attached, by operating these micrometers, we can get the precise motion of table in X and Y directions. The range of movement in X and Y will be like 25 mm x 25 mm, 50 x 50, 100 x 100, like this different ranges available. The resolution of these manually driven XY table will be normally 1 micrometer and load capacity that is the work piece weight, which can be mounted on the table will be like 1 kg, 2 kg and different sizes are available.

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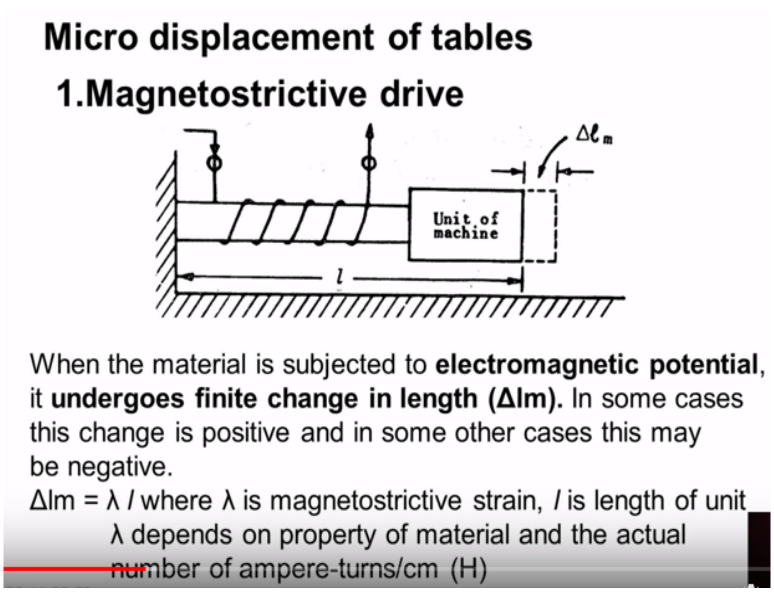

Let us study the magnetostrictive drive used for micro displacement of these tables, we can see the arrangement here, this is the unit of machine or table of the machine, which is moved precisely and here, this is the total length of the unit and here we can see the coil is provided through which the electromagnetic potential is applied and when we apply the electromagnetic potential, the machine tool unit undergoes a finite change in them that is delta M that we can see here.

In some cases, this change is positive that means there will be extension of the unit of the machine and in some cases, it can be negative that means this machine tool unit contracts, so that depends up on the material characteristic delta LM = lambda x l, where lambda is the magnetostrictive strain and l is the length of the machine tools unit. The value of lambda depends on the property of material and the actual number of ampere turns/cm that is H.

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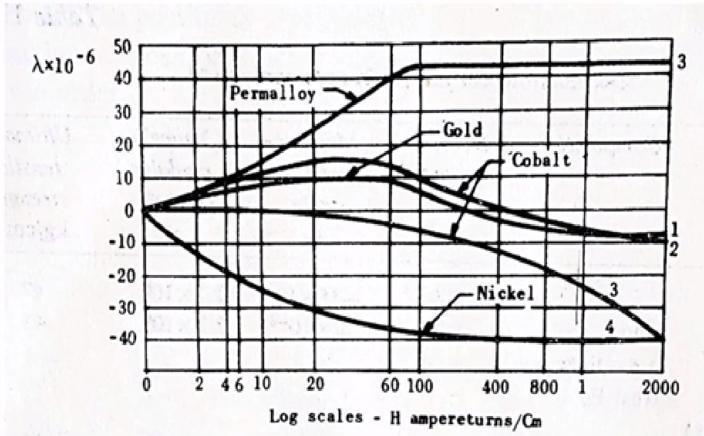

λ – H curves for various alloys

Now, here we can see lambda H curves for various alloys, lambda is the magnetostrictive strain and H is number of ampere turns per cm, so X axis indicates the H values in ampere turns per cm and Y axis indicates the value of lambda, we can see the different materials used for construction of the machine tool table, now the delta lm can be calculated using this relationship delta lm = lambda l, this is equal to, if we take 60 ampere turns/cm per alloy.

Then, the lambda value will be 40 units, so that is 40 x 10 power -6 and let us assume the value of l of the machine tool as 100 mm, then delta lm will be equal to 0.004 mm that means 4 micrometer, like this by adjusting the value of H, we can get the required positioning accuracy. Now these diagrams show the application of magnetostrictive device for giving the final displacement.

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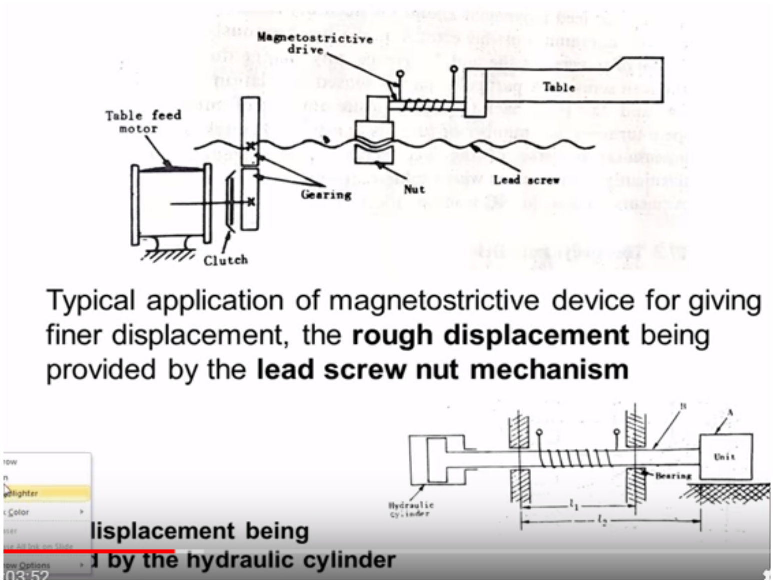

This is the machine tool table, which is to be positioned precisely, so we can see the arrangement, this is the motor for table feed, we have clutch and gearing arrangement and then lead screw with nut. Rough displacement can be given by using the lead screw in it and final movement can be given by the magnetostrictive drive and in is diagram, we can see the rough displacement being provided by the hydraulic cylinder and final displacement of the unit is provided by using the magnetostrictive drive.

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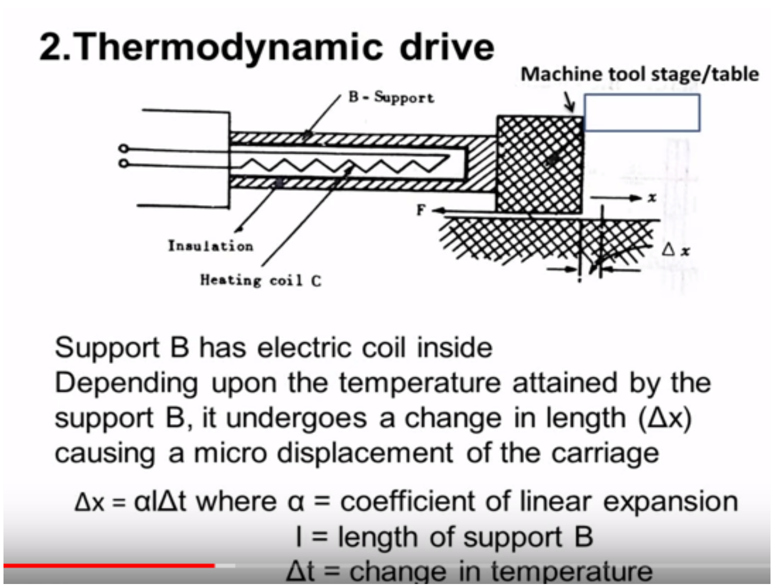

Now, let us study another type of drive used in machine tool tables. This is thermodynamic drive used for very précised movement of machine tool stages, also known as machine tool tables. Now the arrangement is like this, this is the body of the machine tool and this is the support B and this is the machine tool stage, which will move on the guideline and X is the movement that is needed and inside the support B, we have electric coil and current will be passed through this coil and this coil gets heated up and hence the support B will also be heated and it expands.

The support B has electric coil inside depending up on the temperature attained by the support B, which depends up on the current that is passed. It undergoes change in length delta x, we can see here, this table moves to this position depending up on the temperature that is attained by this support B.

Because of expansion of support B, the machine tool will move by micro displacement delta x, so delta x can be calculated by alpha x l x delta t, where alpha is coefficient of linear expansion, which depends up on the support material, l is the length of the support B, so l = length of the support B and delta t is changing at temperature.

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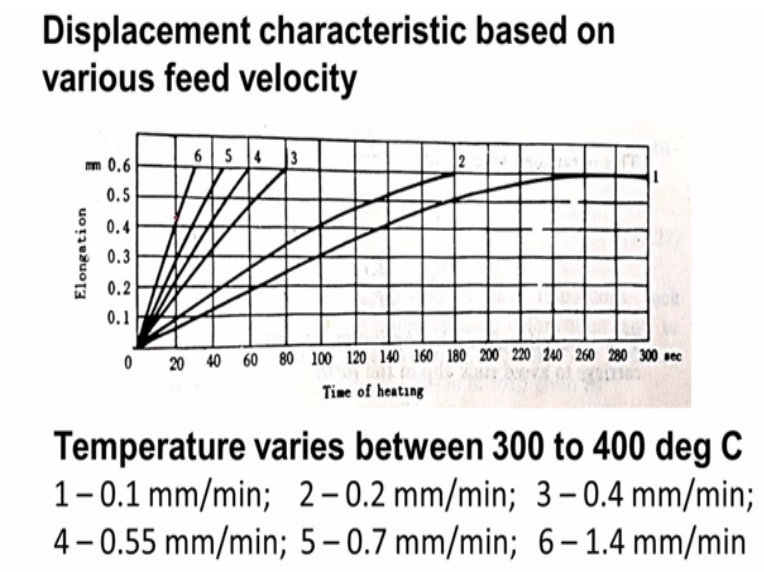

Now, you can see some of the displacement characteristic for a particular material based on various feed velocities, you can see X axis is time of heating in seconds, elongation in terms of millimeter, so the temperature varies between 300 to 400 degree celsius and are available for different feed velocities, now if you take very slow heating as shown by curve 1. If we heat for about 60 second that is 1 minute, then the elongation of the support material will be about 0.2 mm, like this by adjusting the heating time, different displacements can be achieved.

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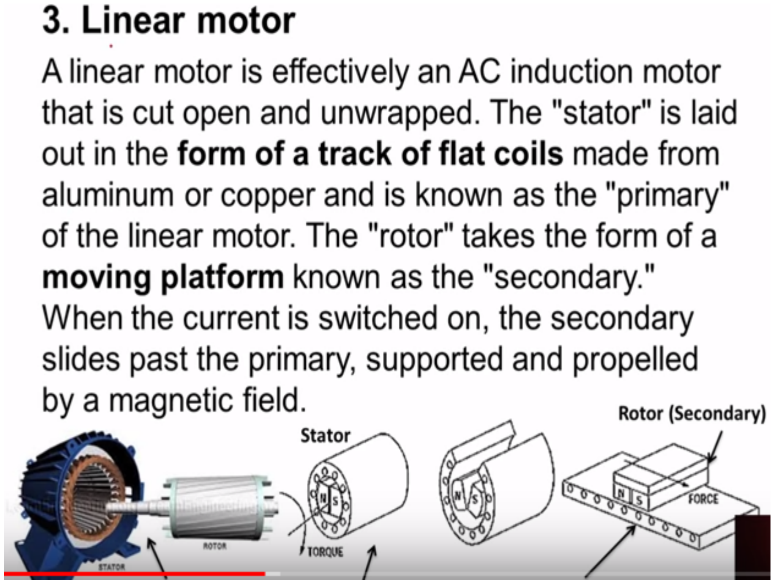

Now, let us study another kind of drive used in precision XY tables, so the linear motors can be used to drive the precision tables. A linear motor is effectively an AC induction motor that is cut open and unwrapped. In this diagram, we can see the conventional rotary is the induction motor, this is the stator coil and the rotor, so when the stator is energized, the rotor starts to rotate. In the linear motor, the stator is laid out in the form of a track of flat coils as shown here.

You can see the stator in the unwrapped form, this stator is also known as primary of the linear motor. The rotor takes the form of a moving platform known as secondary, so this is the rotor portion, which is known as secondary and it is also known as forcer plate, which will move linearly. When the current is switched on, the secondary that is the rotor slides past the primary supported and propelled by a magnetic field.

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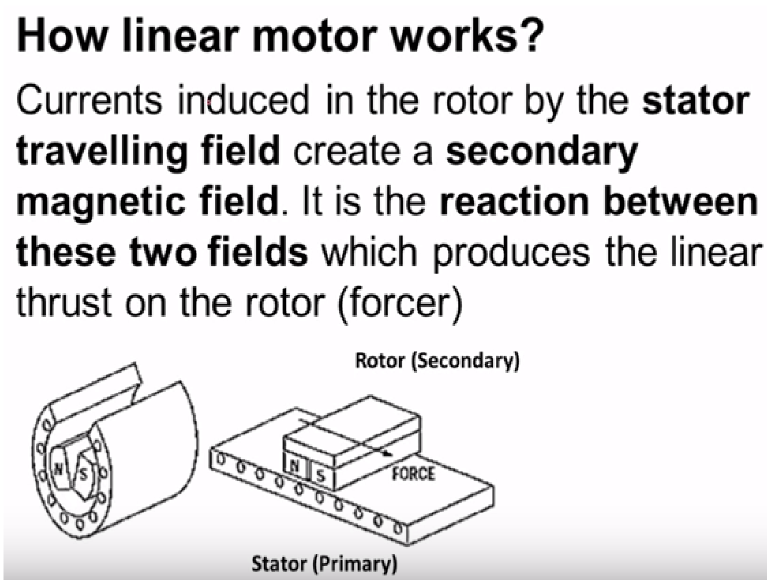

Now, let us study how the linear motor works, so in this diagram, we can see the stator, which is in the form of a flat portion and then we have rotor placed above the stator, so this rotor is supported by mechanical bearings or ear bearing, so when we pass the current to the stator, a magnetic field is induced because of this secondary magnetic field is induced in the rotor. Now these 2 magnetic fields interact or they react between each other.

And this produces a linear thrust on the rotor and hence the rotor starts to move since the magnetic filed in the stator is traveling along with that rotor also starts to move and hence we get the linear motion of the rotor.

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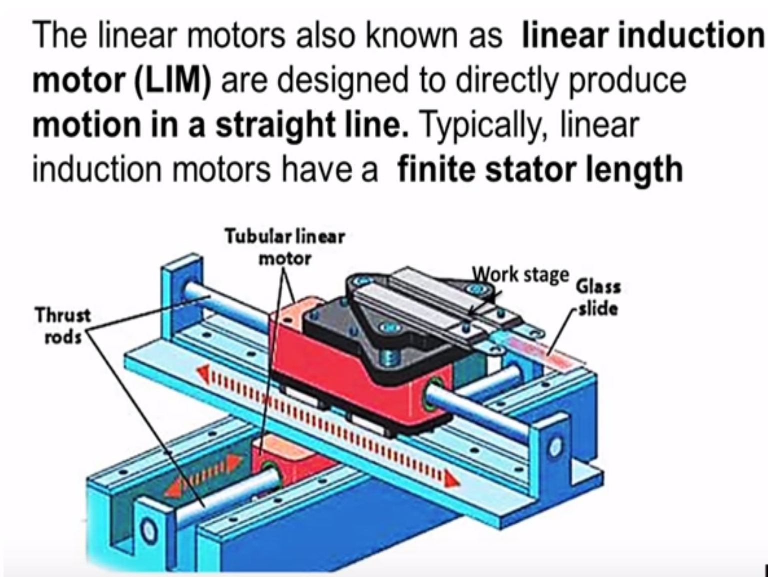

Now, the linear motors also known as linear induction motor, they are designed to directly to produce motion in a straight line typically linear induction motors have a finite stator length that means depending upon the application we have to design the state of it. In this picture you can see the tubular type of linear motor a red colored parts are linear motors and these are thrust rods and this is the work stage where we have to place the work piece

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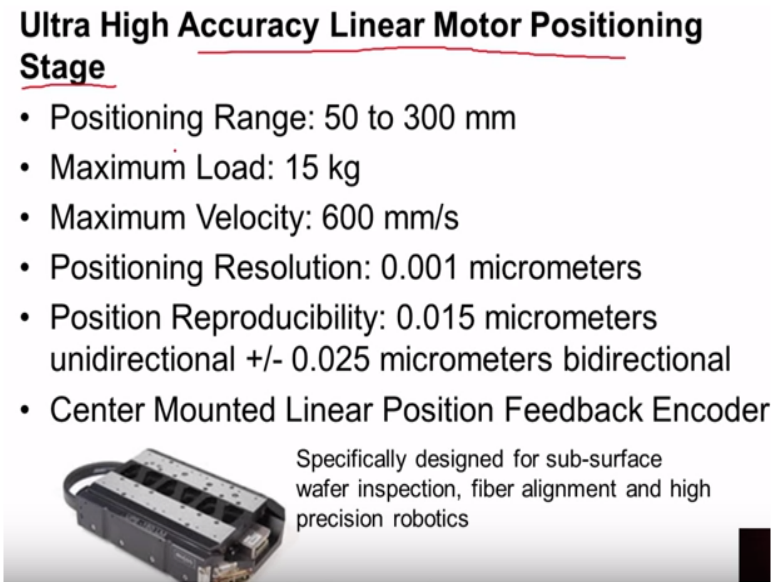

Now ultra high accuracy linear motor positioning stage available in the market with the typical positioning range 50 to 300 mm and they are able to carry a load of 15 kg maximum velocity is 600mm/s, positioning resolution of 0.001 micrometers and they have the positioning reproducibility 0.015 micrometers and +/- 0.025 micrometers bidirectional, centered mounted linear position feedback encoders are provider for feedback.

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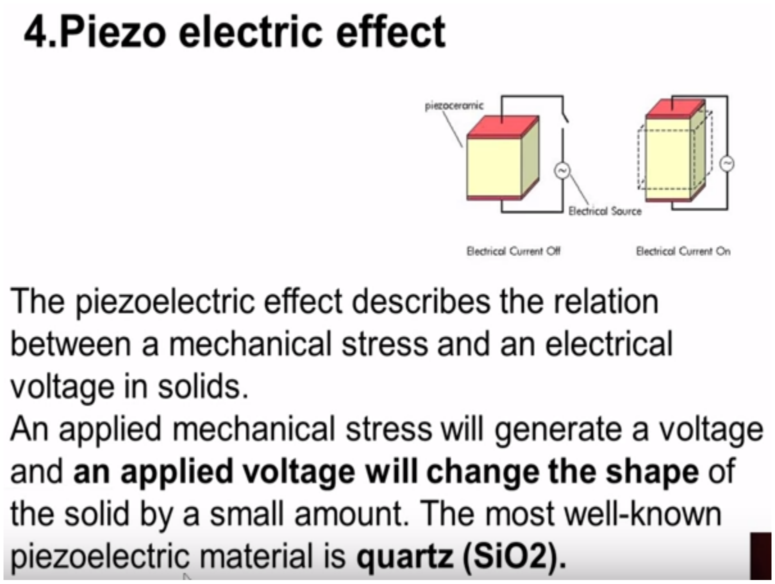

Specifically, they are designed for the sub-surface water inspection fiber alignment and high precision robotics. Now let us discuss another type of dry used in positioners that is piezo electric effect. I can see in the diagrams I can see the solid mass to which the electric current or voltage is applied. In the first case where the electrical current applied is zero and here we can observe that when the electrical voltage applied is deformed in the solid material.

So the effect is known as the piezo electric effect. This effect describes the relation between a mechanical stress and an electrical voltage in the solids. An applied mechanical stress will generate a voltage and an applied voltage will change the shape of the solid by a small amount. The most well-known piezoelectric material is quartz material.

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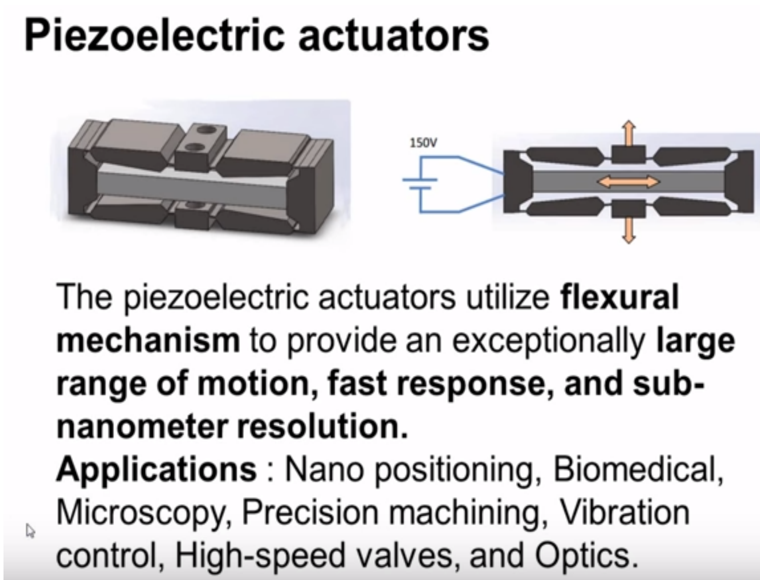

Now the piezo electric effect is used in the piezelectric actuators, used for micro position and nano position application. This is a piezo electric actuators made out of a flexural mechanism the advantage of this flexural mechanism is it is not required any lubrication there is no wear and tear of the parts. Now it is almost made out of single material. Inside we have a piezo electric material to which we have to apply the voltage.

There is a deformation of piezo material with there is a surfaces will move to the perpendicular direction as shown here. So the vertical movement is proportional to the applied voltage. So these flexural mechanisms to provide an exceptionally large range of motion something like 200 micrometer and 300 micrometer and the response is very fast and sub nanometer resolution is possible.

So such piezo electric actuators are used in nano positioning, biomedical, microscopy, precision machining, vibration control and they are also used in high-speed valves and optics.al engineering.

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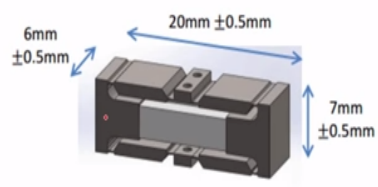
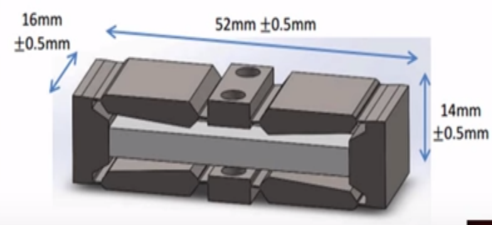
Displacement	>120 um
Voltage	-15V to 150V
Unipolar Disp.	>110 um
Resonance	900 Hz
Force	11 N
Stiffness	0.10 N/um
Capacitance	400 nF



Displacement	>830 um
Voltage	-15V to 150V
Unipolar Disp.	>750 um
Resonance	230 Hz
Force	90 N
Stiffness	0.12 N/um
Capacitance	8.3 uF



Now some specifications we can see here, we can see the dimension of piezoelectric actuators very small length is possible. We can see the total length is 20 millimeter and height is 7 mm and width is 6 millimeter, such a miniature actuators are available. the voltage applied varies from -15 to 150 volts to 150 volts that is vertical movement the displacement range is from zero to 120 micrometer.

So depending upon the applied voltage they can have the displacement in terms of nanometers and you can see another piezoelectric actuator of bigger size. Total length is 52 millimeters width this 16 mm and height is 14 m and the displacement range is obtained is 830 nm and you can see a force that can be applied using a piezoelectric actuators 90 Newtons.

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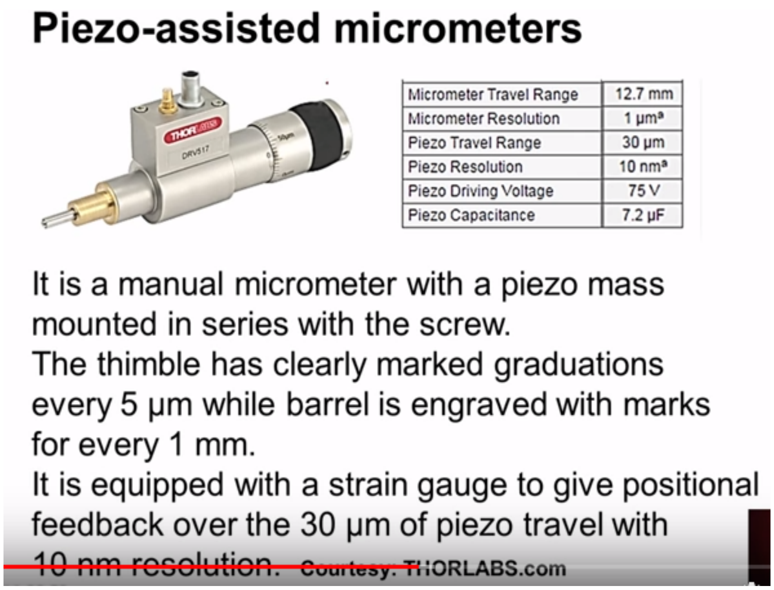

Now you can see now the piezo-assisted micrometer in this picture and it is manually operated with piezoelectric mass is mounted in series with the screw so inside the micrometer screw mass is fixed in series. you can see this is a conventional micrometer bearing can give a larger displacement and the final displacements are given by the piezo mass, you can see the thimble here a graduated.

The symbol has clearly marked graduations every 5 micrometer while barrel is engraved with marks for every 1 millimeter it is equipped with a strain gauge to give a positional feedback over the range of 0-30 micrometer of piezo travel with 10nm resolution, so here we can see the manual micrometer travel range is up to 12.7mm and micrometer resolution is 1 micrometer cube whereas piezo mass travel range is 30 micro metre up to 30 micrometer the piezo resolution is 10 nm.

So piezo driving voltage is up to 75 volt, now in this picture you can see a high load precision piezo nano positioning Z stage that means you can get a vertical movement in the Z direction. So nano positioning is possible in vertical direction. So it has encoder with feedback of resolution of 3 nm and minimum incremental motion of 100 nm and the total travel range is up to 12.5 mm in the vertical direction and can carry a load of up to 12 kg. As it is high load precision nano positioning Z stage.

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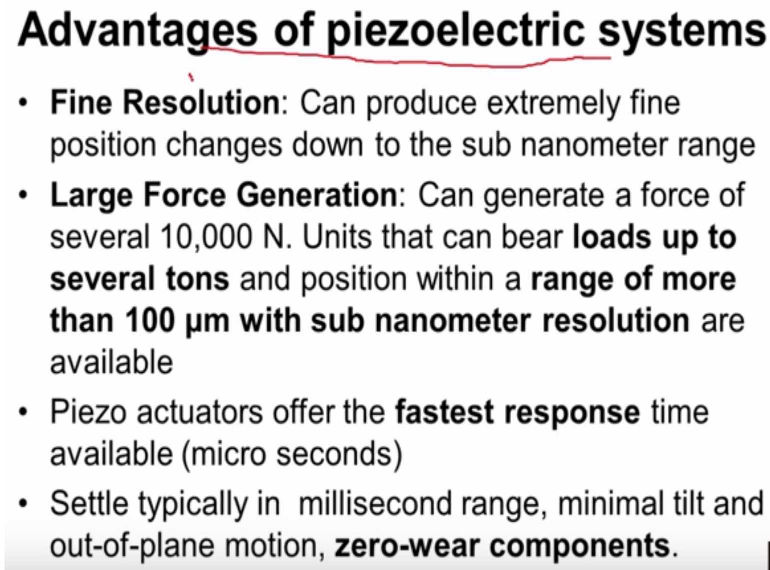

Now what are the various advantages of piezo electric systems you can get a very fine resolution of sub nanometer range so it is extremely fine position is possible. The work pieces can be moved to a very fine accurate position and these piezoelectric systems are able to produce a large force generation. They can generate a several 10,000 Newton and piezoelectric systems are available which can bear loads up to several tons.

And position within a range of more than 100 micrometer with sub nano metre resolution. These piezoelectric actuators offer the fastest response time that is positioning can be achieved within a fraction of microseconds and the settle typically in milliseconds, minimal tilt and out of plane motion and zero wear components is the added advantage of Piezoelectric actuators.

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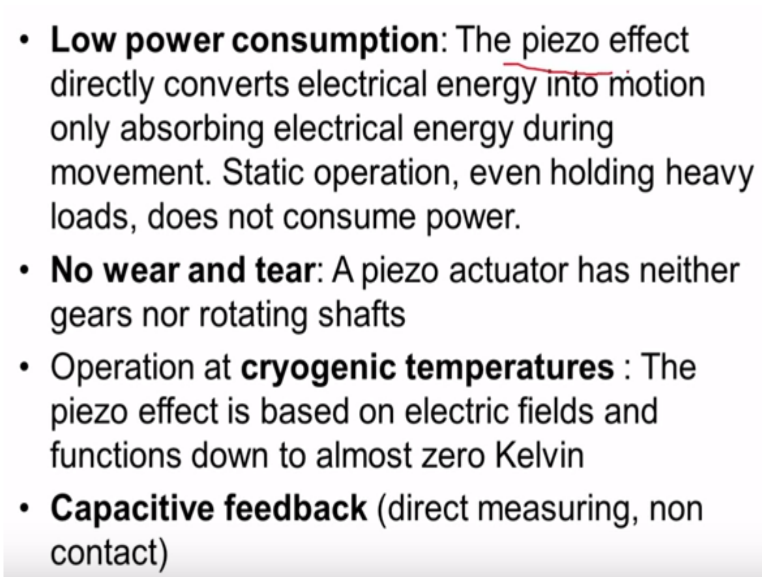

The power consumption is very low, the piezo effect directly converts electrical energy into motion only absorbing electrical energy during the movement otherwise there is no absorbing of electrical energy. Static operation even holding heavy loads does not consume power. Motion and nowhere near motion only during the motion power is consumed.

No wear and tear, and there are no gear or rotating shafts and operation at cryogenic temperatures are possible the piezo electric effects is based on electric fields and functions down to almost zero kelvin and the capacitive feedback is possible, which is direct measuring and non-contact.

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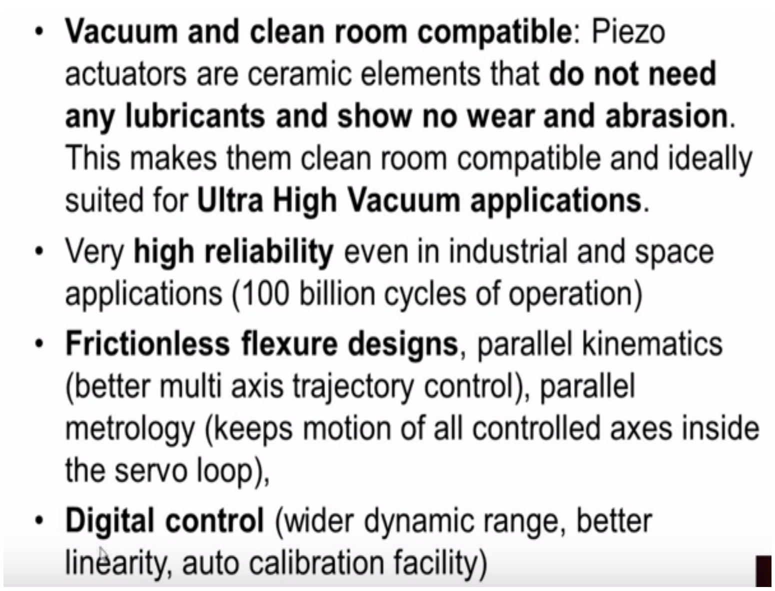

A vacuum and clean room compatibility is there with these piezo actuators and piezo actuators are ceramic elements that and there is no problem operation any lubricants and show no wear and abrasion make them clean room compatible and ideally suited for ultra high vacuum applications and its reliability is very high and they can be used in industrial and space applications where the cycle of operation is as high as 100 million cycles.

And they perform frictionlessly because of the flexure design better multi axle trajectory control and parallel metrology which keeps the motion of all controlled axes inside the server loop and the digital control is also possible with wider dynamic range and better linearity an auto calibration facility is also available with the piezo electric actuator.

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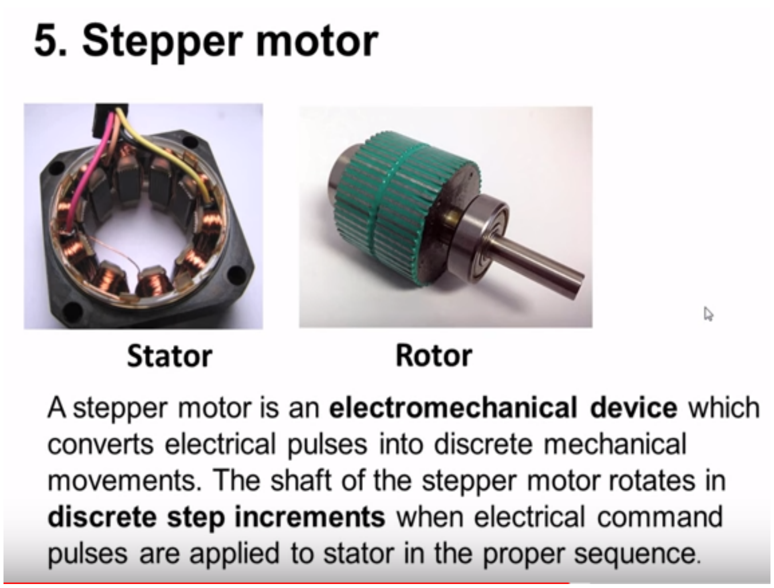

Now let us discuss about the stepper motor which is used in the positioning stages we can see the main parts of the stepper motor which has the field windings and these field windings are energized by supplying the electrical pulses and when the electrical pulses are given to the windings the rotor of the motor is attracted and it starts to rotate. the shaft of the stepper motor rotate in discrete step increments when the electrical command pulses are applied to the stator in the proper sequence.

So when higher rpm is required we have to increase the electrical pulse rate and when very slow speed is needed we have to decrease the pulse rate apply to the stator in this the actual speed of the motor and we can also control the rotation angle by controlling the applied electric pulses.

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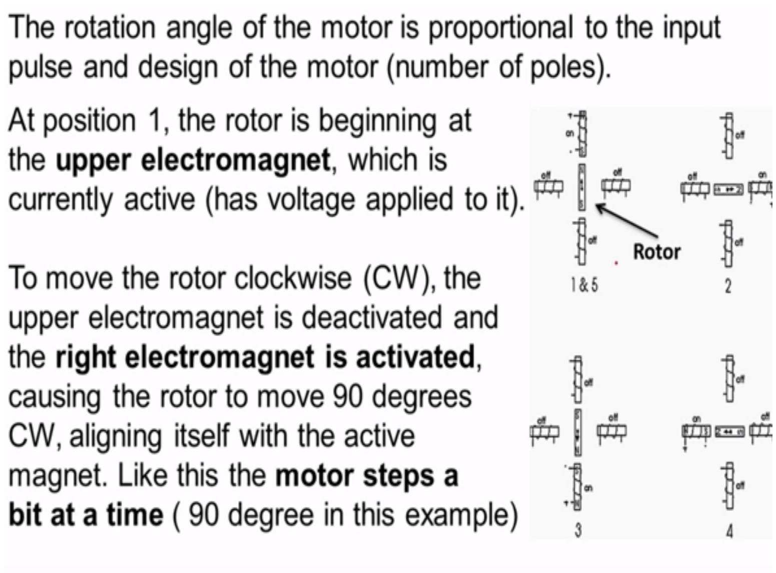

I can I can see the working of the stepper motor and position 1 and this will be position 1 the rotor is beginning at the upper electromagnet this is variants with the voltage applied becomes electromagnet and it attracts. So rotor is in line perpendicular with this upper electromagnet. So if you want to move the rotor in the clockwise direction that means we want to take the rotor in the clockwise direction.

What we have to do is we have to turn off the voltage applied to the upper electro magnets and we have to switch on the voltage supply to the right side of the pole so this becomes the electromagnet and it attracts the rotor and now we can see the rotor has turn to 90 degrees and it gets aligned to the particular active magnet like this the motor steps a bit at time, in this case 90 degree per pulse so if you want a very minute rotation then we have to increase the number of the pose.

So here we have very short and less number of poles. By increasing the number of poles this rotation angle per step can be reduced. We can have 1 degree rotation half degree rotation fraction of angle rotation are possible by the proper design of the motor. Now this processes repeated in the same manner at the south and west electromagnet.

Now we can see in the position number 3, the power supplied the electric volt is switched off and the power was applied to the south is on and this acts as an electromagnet and attract the rotor and we can see the rotor is further rotated and aligned with the south electromagnet and in the 4th position see the voltage supply to the south is switched off and there are west electromagnet is in action. so the rotor is rotated in this fashion.

So like this it can rotate the electromagnetic field we can continue we can rotate electromagnetic field by using a microcontroller and hence we can have the continuous rotation of the rotor at required rpm and we can stop the rotor at any desired position depending on the requirement.

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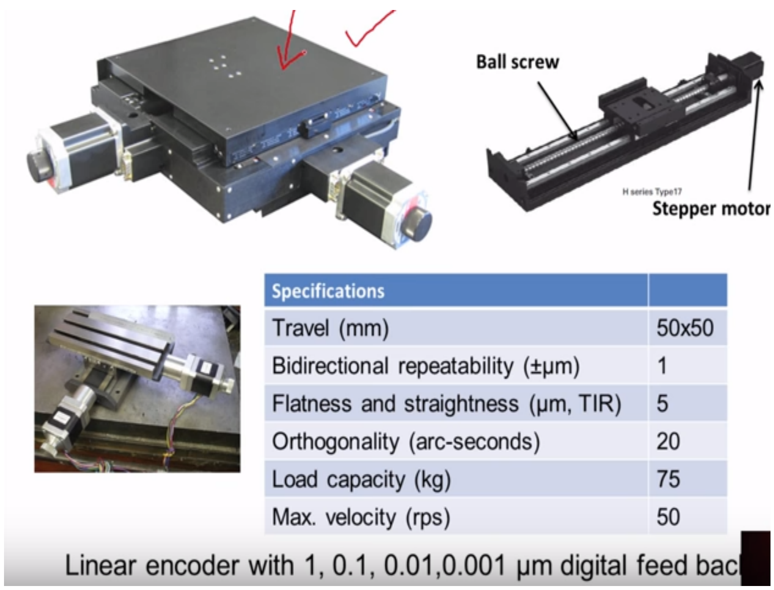

Now in this picture we can see the XY table in which we have to mount the work piece which is to be position rotary stepper motor for x axis and we have one more stepper motor for y axis. We can see another material XY table directional movement and y directional movement so we have one stepper motor x movement and 1 stepper motor movement and you can also see the t-slot mounting of the work piece on the table.

So we can see the stepper motor is coupled with the screws the coupling over here and is properly coupled so the stepper motor is stepper motor is converted to linear X having the version of the table. This is ball screw mechanism. Now some specification we can see in the table of travel of 50 x 50 millimeter or any desired travel can be obtained. The bidirectional repeatability of such and alignment is + or -1 micrometer.

Flatness and straightness movement of the table is 5 micrometer and Orthogonality movement of Orthogonality is arc-seconds. Antilog table and the tables can be designed to 75 kg and maximum velocity that is 50 rps that is 50 rotation per second is possible. We can always integrated the encoders with feedback arrangement to required resolution like 1 micrometer, 0.1 micrometer, 0.001 micrometer are required resolution resolution,0.001 micrometer resolution depending upon the precision and accuracy required.

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Dimensions Unit: mm

Table reference number	Stroke (nominal) S	Stroke (limit)	Length L	Length P	Length n	Mass (kg)
XY-HS0010-34P*	100	110	328	0	6	9.0
XY-HS0020-34P*	200	210	428	1	8	10.0
XY-HS0030-34P*	300	310	528	2	10	12.0
XY-HS0040-34P*	400	410	628	3	12	13.0
XY-HS0050-34P*	500	510	728	4	14	14.0
XY-HS0060-34P*	600	610	828	5	16	16.0
XY-HS0070-34P*	700	710	928	6	18	17.0
XY-HS0080-34P*	800	810	1 028	7	20	19.0

Specifications

Table reference number	Table specifications (µm)			Ball screw lead and inertia of movable parts ($\times 10^{-4}$ kg·m²)		Starting torque (N·cm)		Transportable mass (kg) Horizontal
	Repeatability	Positioning accuracy	Backlash	Ball screw lead 5mm	Ball screw lead 10mm	Ball screw lead 5mm	Ball screw lead 10mm	Ball screw lead 5-10mm
XY-HS0010-34P*	±2	30	5	0.11	0.15	20	30	56
XY-HS0020-34P*				0.15	0.19			
XY-HS0030-34P*	±3			0.19	0.23			
XY-HS0040-34P*		40		0.23	0.27			
XY-HS0050-34P*				0.27	0.31			
XY-HS0060-34P*	±5			0.31	0.35			
XY-HS0070-34P*		50		—	0.39			
XY-HS0080-34P*					0.43			

Maximum speed Unit: mm/s

Lead \ Stroke	~600mm	700mm	800mm
5mm	250	—	—
10mm	500	500	500

1. The values of table inertia and starting torque do not include the coupling and load mass.
2. Refer to the above starting torque for selection of motors.
3. Specifications have no load and may vary depending on load mass.
4. Specified motor, driver, sensor, etc. can be selected and mounted.
5. Please contact NSK for special specifications.

Select appropriate encoders and select appropriate lead on the ball screw. Now we can see some specifications here the XY table with stepper motors are available with different stroke length 100 millimeter, 200 millimeter and even 800 millimeter even more than that is also possible. The repeatability is also plus or minus 2 micrometer can be achieved with the position accuracy of 30 micrometer, 40 micrometer, 50 micrometer can be achieved.

So by having proper design of positioning accuracy of 1 microns, 2 microns also possible. So we can see maximum speed so in the ball lead screw is having the lead 5 millimeter then speed of 250 mm is also possible. The screw width 10 mm lead ball screw a speed of 500 mm per second is also possible.

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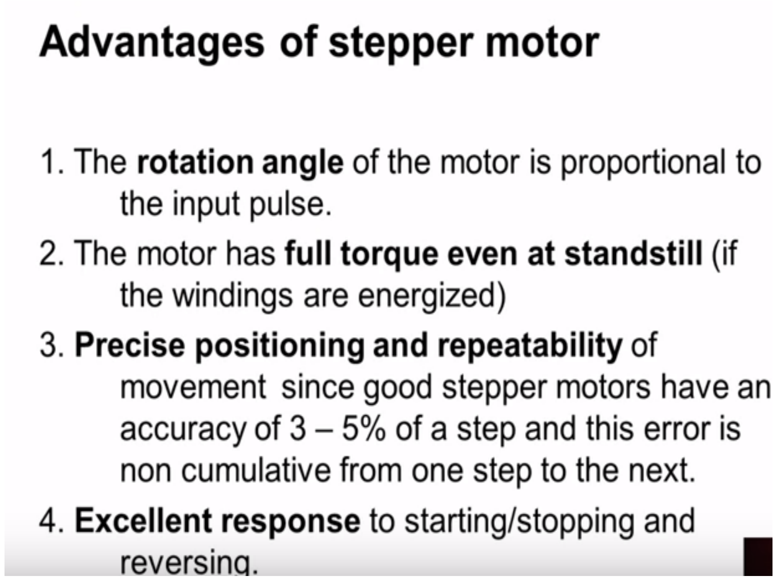

Now what are the advantages of stepper motor controlling the rate of input pulse we can control the rotation angle and position the rotor which is design rotation angle. The motor has full torque even at stand still when the windings are energized. So precious positioning and repeatability of moment is possible since the stepper motors have an accuracy of 3 to 5% office step and this error is a non-cumulative from one step to the next step. Excellent response to starting and stopping and reversing is also possible in terms of milliseconds.

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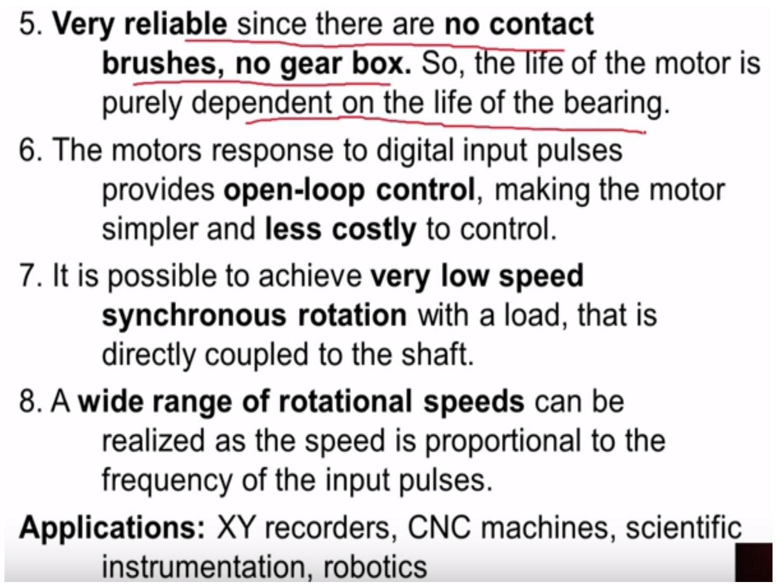

Very reliable this stepper motors are very much reliable since there is no contact brushes no gearbox. So the life off the motor is purely dependent on the life of the bearing what we use. The motor the motors response to the digital input pulses hence open loop control is possible making the motor very simple and less costly to control and it is possible to achieve very low speed synchronous rotation with the load that this directly couples to the shaft.

By adjusting the pulse rate we can have a wide range of rotational speed can be obtained as the speed is proportional to the frequency of the input pulses we can have very low speed. We can have high speed also so these step up motors have many applications in XY recorders CNC machines scientific instrumentation for positioning of the work pieces and they are also used in the robotics for proper positioning of the work pieces.

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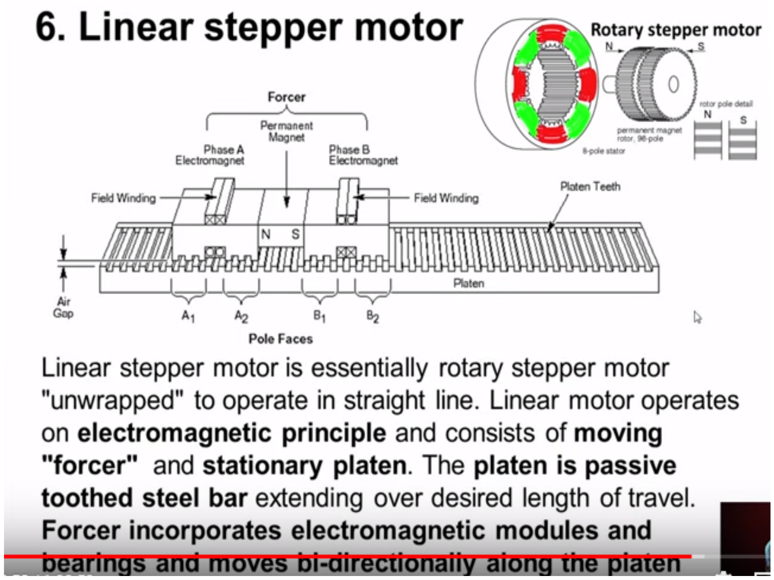

Now let us start another type of system used in stages. Now in the picture you can see this linear stepper motor. It is constructional picture you can see here. We have a platen teeth cut on it and then forcer unit with 2 phases of electromagnet phase a and phase b. In between you have a permanent magnet. You can see this is the stator, which is having the field windings.

Here the forcer unit pitch modes has the field windings they become the electromagnet where is the stator, the platen is the stator and which is not having any electric field windings. Basically, the linear stepper motor is the rotary stepper motor unwrapped in a straight line to operate on a electromagnetic principle and they consist of a moving force and stationery platen.

So the stationery platen is fixed to the position stages and the forcer will be moving and the work piece in the table is mounted on the forcer unit. The platen is passive tooth steel bar without any windings it extends over desired length of the travel. The forcer incorporates electromagnetic modules that means phase 1 and phase b electromagnet and it runs along the length of the stepper, the stator the forcer unit moves along the stator and it is supported by bearings and it can move in the both directions.

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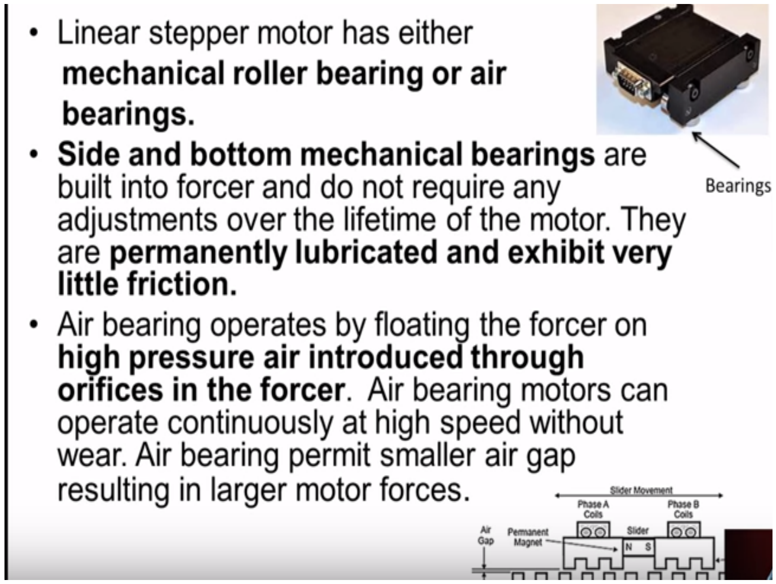

Now in this picture you can see a forcer unit, so here there will be electromagnetic modulus will be there. We can see the bearings in the side as well as in the bottom portion .linear stepper motor has either mechanical roller bearing are also fixed to this or air bearings or also used in this linear stepper motor. The side and the bottom mechanical bearing are built into the forcer they are fixed to the forcer.

They do not require any adjustments over the lifetime of the motor. They are permanently lubricated and exhibit very little amount of friction. And we can see here if the air bearing are used we can see that a gap between the forcer unit and the platen and the forcer unit, the bottom of the forcer units will be orifices. So through this orifices compressed air is allowed and because of the air pressure the platen, the forcer it will float and then it will move in a linear direction.

Air bearing motors can operate continuously at high speed without any wear because since there is no metal to metal contact there is no wear of parts. air bearing permits smaller air gap resulting in larger motor forces.

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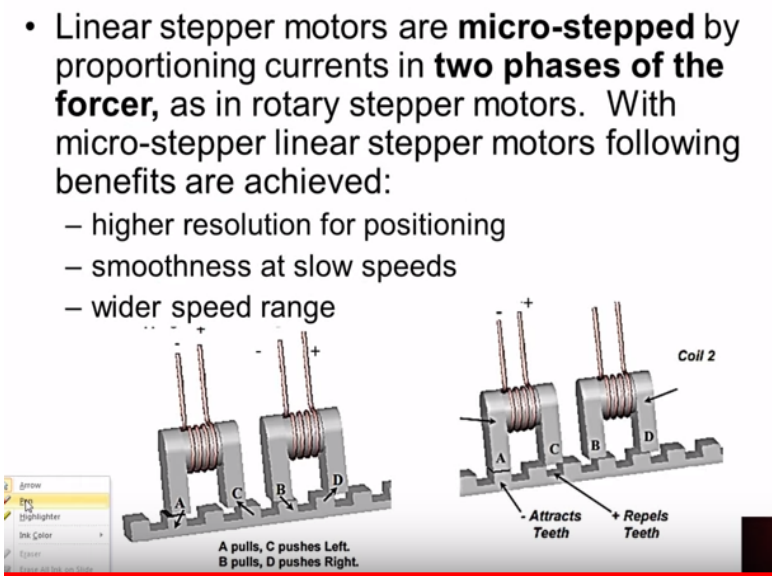

Now linear motor, linear stepper motors are micro stepped by proportioning the current into 2 phases. In this picture, we have observed the 2 pages 2 phases phase a and phase B, so like this is by proportioning the current micro stepping can be achieved to have a higher positioning the micro stepper, linear stepper motors following benefits can be achieved higher resolution for required positioning.

And it runs very smoothly at slow speeds and then why does speed range can be obtained. Here we can understand the micro stepping one phase of the forcer. When one coil one ace powered I can see here there is attraction between the 2 surfaces and here there is repulsion resultant force will move by 1 step this is known as full stepping and when both coil 1 and 2 are powered.

At that time together here at A there is some pulling force and B also there is a pulling force because of this the forcer will move half a step. This is known as half stepping. So this process is known as micro stepping very high resolution can be obtained.

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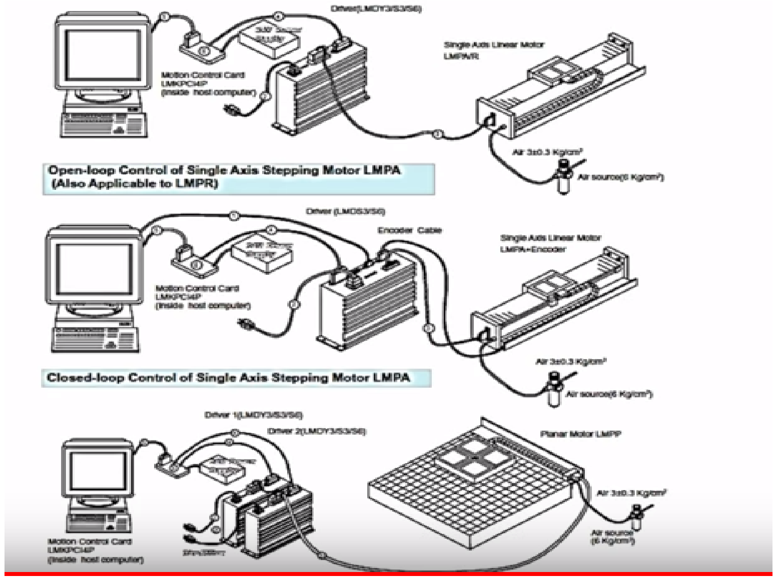

Now we can see the complete arrangement of open loop single axis stepping motor the linear stepper motor now you can see it and you can see a bearings are provided in this air at a pressure of 3 bar is supplied, so that can air bearings can be operated . Here there is in the open loop control there is no feedback of the position of the forcer. Where in this case this is closed loop control of single axis stepping motor again this is air being operated.

We can see encoder are provided for feedback of the position of forcer and this is open loop when are stepping planner stepping axis that is stepper motor which can move in x direction as well as in y direction.

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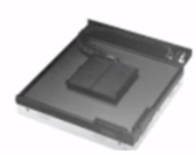
Spec	Item	Symbol	Unit	LMPA 341/342	LMPA 541/542
*PERFORMANCE	Max. Thrust	T_m	(N)	60	80
	Holding Force	T_s	(N)	70	100
	Resolution	R_s	(mm/stp)	0.001~0.01	0.001~0.01
	Repeatability	R_p	(mm)	0.002	0.002
	Accuracy	A_c	(mm)	±(0.005~0.04)	±(0.005~0.04)
	Max. Vel.	V	(m/s)	1.5	1.5
	Max. Acc.	A	(m/s²)	20	20
FORCER	Phase	ϕ	ϕ	2	2
	Current	I	(A)	3	3
	Mech. Pitch	P_t	(mm)	0.64/1.28	0.64/1.28
	Length	L_f	(mm)	124	124
	Width	W_f	(mm)	68	83
	Height	H_f	(mm)	68	83
	Air Gap	T_a	(mm)	0.015	0.015
	Air Pressure	P_a	(bar)	3.0±0.3	3.0±0.3
	Air Flow	F_a	(ℓ/min)	8	9
	Mass	M_f	(kg)	0.65	0.8
	Op. Temp.	T	(℃)	0~50	0~50
	Fix. Distance	$A_f x B_f$	(mmxmm)	116x42	116x57
STATOR	Length	L_s	(mm)	300~1000	300~1000
	Width	W_s	(mm)	50	65
	Height	H_s	(mm)	50	65
	Specific Mass	M_s	(kg/m)	12	15
	Fix. Distance	$A_s x B_s$	(mmxmm)	100x72	100x87

Linear stepper motor



Linear planar stepper motor
(Dual axis motor)

Now you can see some performance details of commercially available linear stepper motors maximum thrust on the forcer it can be 60 Newtons or 80 Newton depending upon the model what we use. And the holding force will be 70 Newton entertain you ten sports the resolution by step is as low as 1 micron .the resolution can be obtained repeatability of 2 microns are possible and position accuracy of plus or minus 5 micron is this possible with this type of linear stepper motors maximum velocity of 1.5 metre per second is achieved.

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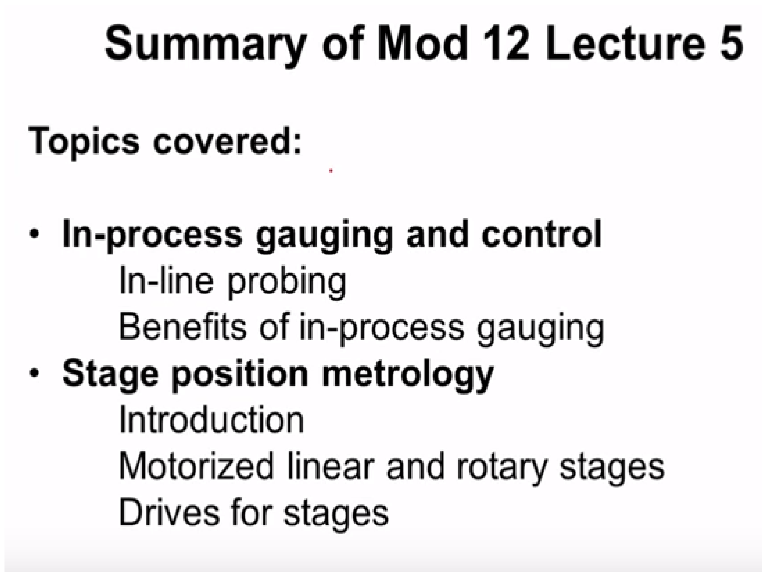

Now with this we will conclude module 12 lecture 5. In this lecture we discussed about the in line probing and benefits of in process gauging. And we discussed about the basics of state position metrology and motorized linear and rotary stages and then different kinds of drives used for moving the stages with this we will conclude. Thank you.