Advanced Machining Processes

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Module - 02
Lecture - 06
Magnetic Abrasive Finishing

Welcome to the course on advance machining processes. Today we are going to discuss on a mechanical type advance finishing process that is called magnetic abrasive finishing process. So there are different kinds of conventional finishing process whatever we have heard like grinding, honing, lapping operation okay but all these grinding, honing, lapping operation it is very difficult to control the forces finishing forces but in case of this nonconventional machining or finishing forces you can control the finishing forces by using a magnetic field like in magnetic abrasive finishing process.

So that is why when you are trying to automate the process by using any automatic process so this conventional finishing process are very difficult to control finishing forces but nonconventional finishing forces by using this magnetic field you can control the finishing forces okay. So one more thing is that this adaptability of the polishing media like when you are using grinding at that time you cannot polish any kind of complex freeform surface but by using this magnetic abrasive finishing so this magnetic abrasive finishing process you can polish any kind of complex freeform surfaces okay.

Generally by this magnetic abrasive finishing process generally cylindrical and flat workpieces are polished but any kind of complex freeform surface also polished can be polished by this magnetic abrasive finishing process by using a suitable fixture okay.

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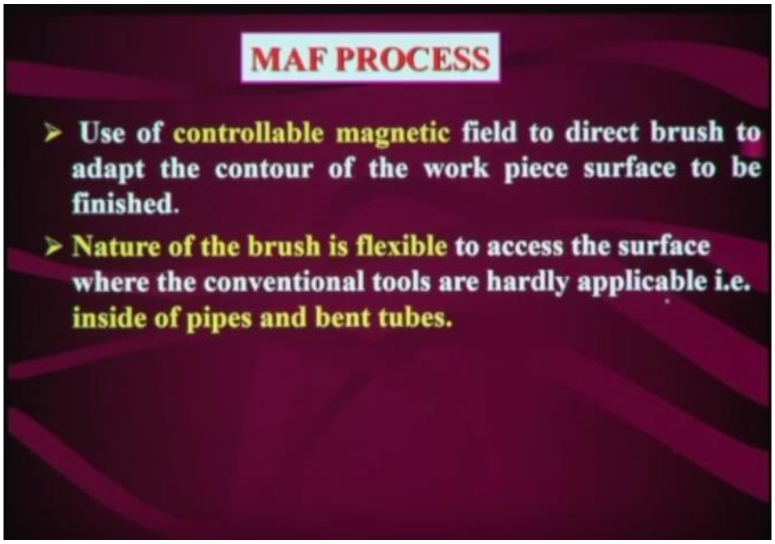

So in MAF process use of controllable magnetic field to direct the brush to adapt the contour of the workpiece surface to be finished and nature of the brush is flexible okay. So whatever we told that flexible means it can polish any kind of complex freeform surface because of this flexible brush. So this nature of the brush is flexible to access the surface where the conventional tools are hardly applicable okay, inside pipes or bent tubes okay like you want to polish at the internal surface of the tube so any kind of conventional polishing process is difficult to polish at the internal surface of the tube or in any inaccessible areas. So in those inaccessible areas magnetic abrasive finishing process can be used to polish.

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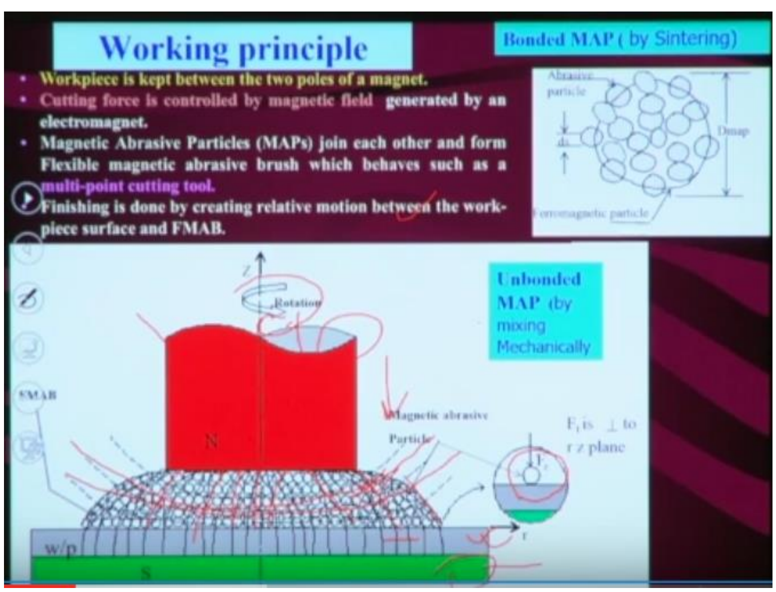

So what is the working principle? So working principle is that workpiece is kept in between the 2 poles of the magnet okay, cutting force is controlled by the magnetic field generated by an electromagnet or you can use permanent magnet also. So nowadays very high strength permanent magnets are available like radium, iron, boron. So using this permanent magnet with highest grade you can get up to 0.6 tesla magnetic field okay. So you can use electromagnet or you can use permanent magnet.

The advantage of this electromagnet is that by changing the current to this electromagnet you can change the magnetic field which is not possible by in case of permanent magnets okay. So this magnetic abrasive particles join each other and form a flexible magnetic abrasive brush which behaves such as a multipoint cutting tool and then finishing is done by creating relative motion between this workpiece surface and flexible magnetic abrasive brush.

So this is the magnet here. So this is the magnet here. You can see this is the so you can see this is the magnet here. So this is the north pole of this magnet and here you can see this here where here it is used a magnetic base material okay. So because we have used this north pole here and then this is the magnetic waste plate here and this is the workpiece that has to be polished that workpiece surface that has to be polished and in between this north pole and this workpiece this magnetic flexible magnetic abrasive particles are kept okay.

So this flexible magnetic abrasive particles are actually iron particles. These are 99.9% (4:40) iron particles and abrasive particles are mixed with these with these iron particles and they are made a homogeneous mixture okay. So some binding some binding material like binding fluid like some grinding fluid actually it is mixed for binding this abrasive particles with the iron particles okay.

So while you are applying some magnetic field what happens this magnetic abrasive particles magnetic particles actually it will form chains along the lines, magnetic lines of force. So this is the magnetic lines of force. Along this magnetic lines of force this magnetic abrasive particles will form the chains okay.

So this abrasive particles are actually held in between this chains okay. So this abrasive particles are held in between these chains and these lines are magnetic equipotential lines okay so these lines are magnetic equipotential lines or perpendicular to that these lines are actually magnetic field lines okay. So these abrasive particles will form chains along this magnetic along the along the line of magnetic force okay. So these abrasive particles are held in between this magnetic particles and it will form a flexible magnetic abrasive brush okay so it will become very solid kind of thing and it will follow flexible magnetic abrasive brush okay so it is very hard also. Now we are giving a rotating motion to give a relative motion between this tool between this tool and the workpiece surface okay.

So when you are giving a rotating motion here rotating motion of this magnet okay so this flexible magnetic abrasive brush also it will rotate along with the magnet and because of this relative motion between this abrasive particles and this workpiece surface there is a there is machining will this abrasive particles will remove the surface undulations from the workpiece surface.

Okay so there are 2 kinds of forces are there one is the normal force here because of this squeezing of this tool into the workpiece surface through this magnetic abrasive particles so there is a normal force is there okay so this normal force will help into the penetrating this abrasive particles into the workpiece surface okay into the surface and erosions and this (()) (7:10) because this relative motion between this tool between this abrasive particle on to the workpiece surface on a fixed workpiece surface because of this relative motion okay.

So there is a tangential force will generate. So because of this tangential force this whatever abrasive particle intended into the workpiece surface it will remove the surface annulations from the workpiece surface. So this working principle is very simple. So here unwanted type magnetic abrasive particles are used.

There are 2 types of magnetic abrasive particles one is unwanted type another one is the bonded type. So unwanted type loose magnetic particles and loose abrasive particles are homogeneously mixed using a binding material, binding fluid, generally it is a grinding fluid okay.

So we shall discuss all these kind of bonded and unbounded magnetic abrasive particles later and finishing is done by creating a relative motion between this workpiece surface and the flexible magnetic abrasive brush. So this is the flexible magnetic abrasive brush. So you can see here one individual abrasive particle, it is intended into the workpiece surface because of this normal force and because of this tangential force it will remove the surface annulations from the workpiece surface.

So here you can see this is the bonded type magnetic abrasive particles okay. So in this bonded type magnetic abrasive particles there is a lump magnetic particle is there which is around 200-300 micron okay so and there is a small diamond abrasive particles are there with diameter is small d and bigger size diameter is the capital D is the diameter of the magnetic particles and small these are the small diamond abrasive particles are there so with having small d diameter okay.

So this small abrasive particles are actually sintered into the bigger size ferromagnetic particle by this sintering process okay. So now this will act as a flexible magnetic abrasive particles. So this is a total magnetic abrasive particles. But in this case, in this figure magnetic particles ferromagnetic particles and abrasive particles they are homogeneously mixed, they are not sintered here. So in bonded type this abrasive particles are sintered into a bigger size ferromagnetic particle and unwanted type they are not sintered, they are separate.

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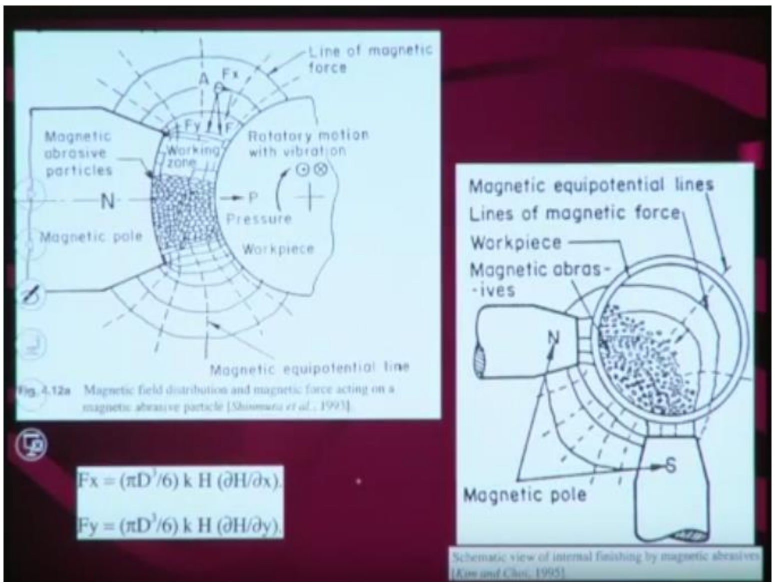

Okay so there are different configurations of magnetic abrasive finishing process, different configurations. Already I told that either cylindrical workpieces or flat workpieces are generally polished by magnetic abrasive finishing process. Suppose if we take cylindrical workpiece here okay, so this is the north pole and north pole this shape actually it is some hemispherical shape is considered to generate a uniform magnetic field on the workpiece surface okay.

So now you can see these are these lines these lines are magnetic line of magnetic force okay. So these lines are magnetic force lines and perpendicular to that magnetic equipotential lines are there. So these lines are magnetic equipotential lines. Now this is the north pole of this north pole of this magnet and this is our workpiece. Now to give the rotating motion okay so these workpiece is now rotated with a high RPM okay with a certain RPM it is rotated. Now in between this north pole and workpiece this magnetic abrasive particles are actually kept and when this magnetic field is applied in between this north pole and and between this workpiece because of this magnetic application of magnetic field this iron particles it will form with chains along the magnetic lines of force. It will create magnetic it will create a pressure normal pressure into the workpiece surface.

So which is shown here so it will create a pressure p into the workpiece surface okay. So because of this relative motion between this workpiece with respect to the magnetic particles okay so it will remove the certain annulation from the workpiece surface. So now if we consider a magnetic particle here, magnetic abrasive particle is here, so there are 2 forces are here. One force is Fx which is turning to this along the turning to the line of magnetic force magnetic force lines and another force is that that is called actually Fy okay.

So these are the 2 components are there. So because of this Fx it will indent into the workpiece surface, it will penetrate, this magnetic abrasive particle it will penetrate into the workpiece surface and because of this Fy this force okay so it will do the surface annulations from the workpiece surface. So this is another configuration here, north pole and south pole actually kept perpendicular to the north pole of the magnet and south pole of the magnet, they are kept perpendicular to each other okay. So this is here in this case this is the magnetic force lines and these are the magnetic equipotential lines okay.

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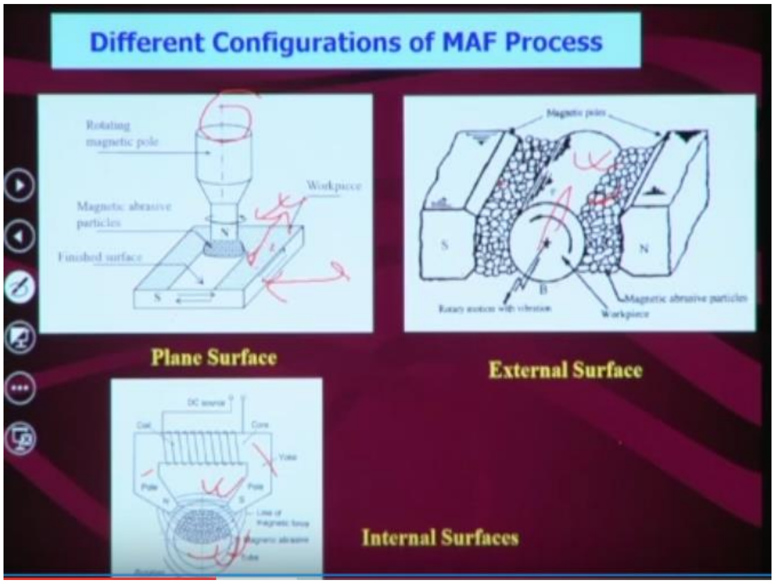

There are another configurations also there. So here in this configuration flat workpieces are kept okay are polished here so this is the north pole of this magnet and this workpiece here actually here this workpiece is actually magnetic workpiece. So that is why south pole is generated into the workpiece surface and in between this north pole and south pole we have kept this magnetic abrasive particles okay and this total workpiece actually it is given x and y this movement is given to polish the entire workpiece surface and also at the same time this magnet also it is rotated with a certain RPM to give the relative motion between the abrasive particles with the workpiece surface okay.

So this is another configuration of the magnetic abrasive finishing process. Here cylindrical workpiece is actually polished. Here this is the south pole and this is the north pole of the magnet and this is the workpiece, it is rotated with a certain RPM okay. So and these are the magnetic abrasive particles are there.

There are another configuration here, electromagnet you can see north pole and south pole they are perpendicular to each other. So here you can see here we are polishing external surface of this workpiece. Here also external surface of this cylindrical workpiece we are polishing and this kind of workpiece polishing magnetic abrasive finishing process you can retrofit into a length machine okay. So a length machine can be converted into a magnetic abrasive polishing machine.

By fixing this workpiece into the tailstock and headstock and another arrangement for fixing the magnets okay. So in this configuration you can see this internal surface of this cylinder actually polished by this magnetic abrasive finishing process. Here also it is rotated this workpiece is rotated with a certain RPM and this north pole and south pole is are fixed here.

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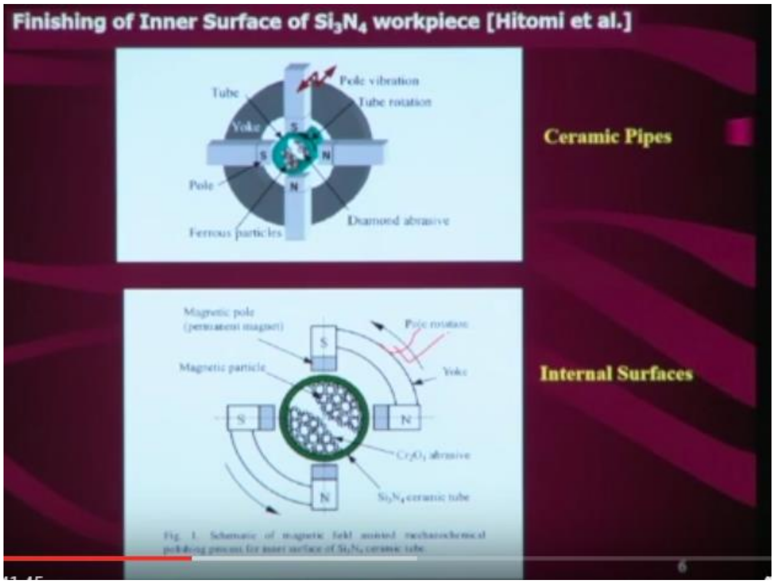

Okay so there are different other configurations are there. Here 4 magnets are kept just outside this workpiece. These are the work done by Shimura et al. Here ceramic pipes are actually polished, internal surface of this ceramic pipes are polished. Here also you can see north pole and south pole, these are perpendicular to each other okay. So here this yoke is connected to increase the magnetic field here and this total yoke along with these magnets permanent magnets actually it is rotated. So here in this case permanent magnets are used, in earlier case electromagnets are used. So these ceramic pipes, internal surface of the ceramic pipes are polished by this magnetic abrasive finishing process okay.

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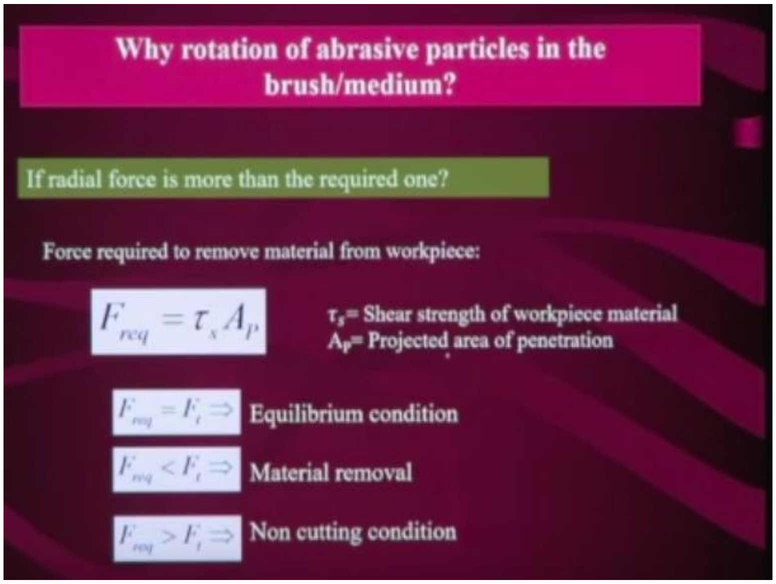

So why rotation of this abrasive particles in the brush. So rotation is important to give the relative motion between this abrasive particles, magnetic abrasive particle, into the workpiece okay. So without this rotation there will not be any tangential force. So normal force is there. So this normal force is required for this indentation or penetration into the workpiece surface and because of this rotational motion there is a tangential force will be generated. This tangential force is required for cutting the surface undulations okay.

So force required to remove the material where tau S is the shear stress of this workpiece material and Ap is the projected area of penetration into the workpiece surface, projected area of this abrasive particles into the workpiece surface because of this normal indentation force. So this projected area multiplied by this shear stress will give the force, required force, for this polishing to take place okay.

So now when this required force is equal to the tangential force, tangential force because of this rotation, so then equilibrium potential will occur. So this finishing is about to start, but when this force, tangential force is greater than your required force equal to shear force, so in that case your shearing action will take place or your cutting action will take place or material removal will take place. But when this required force is greater than the tangential force or tangential force, applied tangential force is less than the required force in that case no cutting action will take place okay. So these are the 3 different conditions are there.

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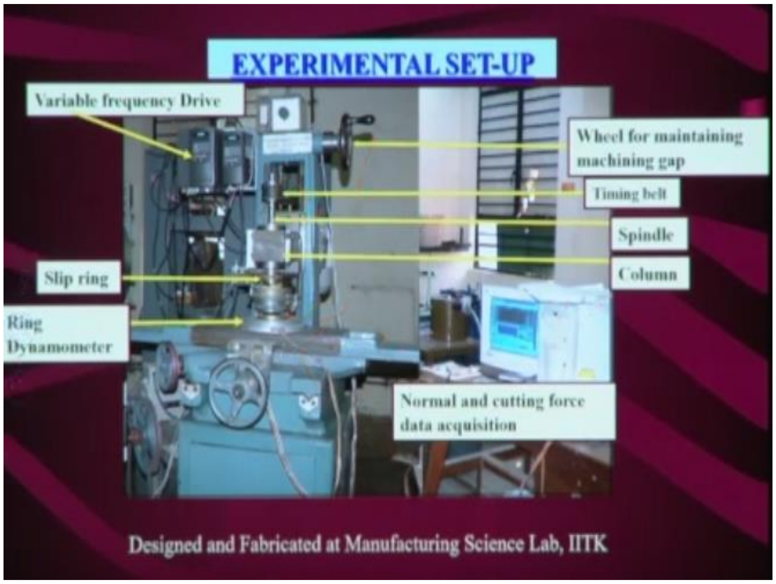

So this is the experimental setup available at IIT Kanpur. So you can see here this is the tool rotation system. There are 2 variable frequency drives are used and 2 motors are used. So here one motor is to rotate the shaft here. This shaft is connected to this magnet. So this magnet shaft is rotated here and another motor is actually to give the this x movement of this tool okay, to give the x movement of this tool this another another motor is used here.

So this wheel is actually used for maintaining the gap between this tool and between the magnet and the workpiece. So there is a timing belt is used so that there should not be any (()) (18:16) friction between this shaft and the motor, motor shaft and this is the spindle and the slip ring is used to give the current to this motor to give the current to this electromagnet and there is a dynamometer, fabricated dynamometer, custom-made dynamometer is dynamometer is used okay, so to calculate the normal force and the tangential cutting force and there is a data intelligent system is used for measuring this cutting force and normal force and the tangential force.

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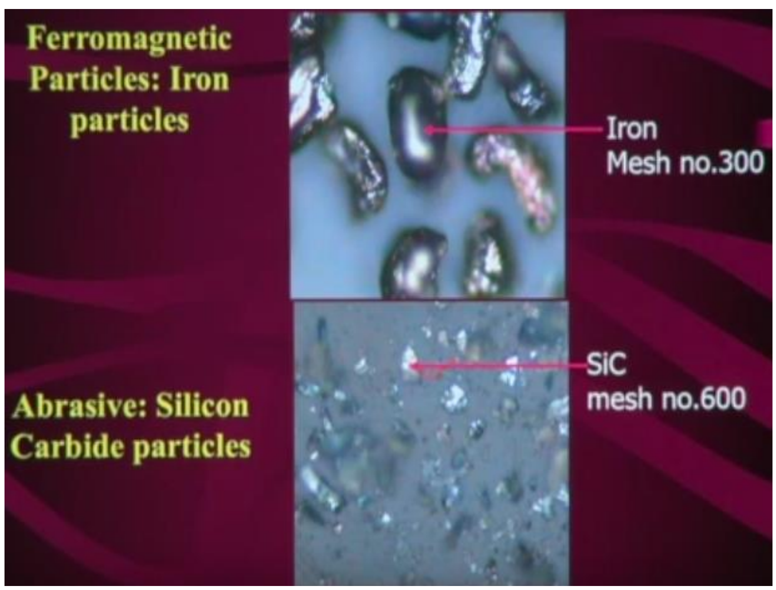

So these are the ferromagnetic particles, iron particles of mesh 300 mesh size and these are the abrasive silicon particles, silicon carbide abrasive particles. So these are the silicon carbide particles with 600 mesh size.

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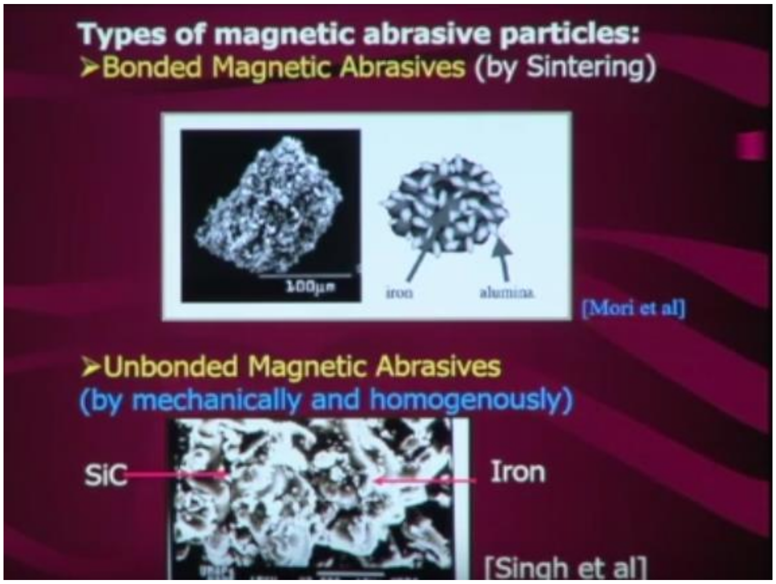

So types of magnetic abrasive particles already I have shown. So this is your bonded type magnetic abrasive particles are here, unbonded type magnetic abrasive particles. Here this in unwanted type this abrasive particles are magnetic particles are homogeneously mixed by grinding oil.

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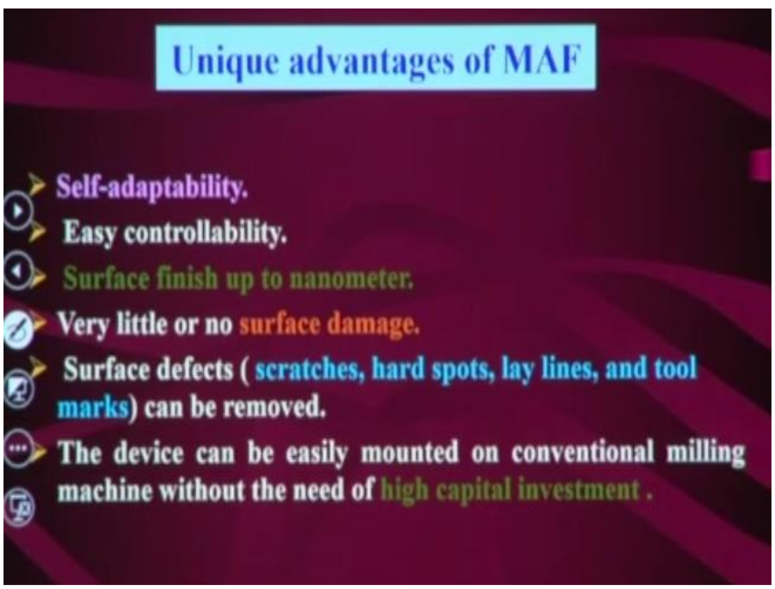

So what are the unique advantages of this magnetic abrasive finishing process? Self-adaptability is one of the advantages. Self-adaptability means it can polish any kind of complex freeform surface. It will take this fluid, this magnetic abrasive particles, magnetic abrasive fluid will take the shape of the surface to be polished. So that is why it is called self-adaptability.

Easy controllability. So this strength of this bonding material or magnet strength of this magnetic abrasive particles, bonding strength of this magnetic abrasive particles are controlled by magnetic force. So by changing current to this electromagnet your strength of this bonding materials or magnetic abrasive particles can be changed.

So easy controllability. Surface finish up to 3 nanometer level. From this process you can get the surface finish up to the nanometer level. Very little or no surface damage. There is very less surface damage because whatever heat is generated it is very less in case of magnetic abrasive finishing process. Surface defects like scratches, hard spots, lay lines, and tool marks can be removed by this process and this device is can easily be mounted on conventional milling machine without the need of the high capital investment.

So any kind of milling machine or grinding machine or lathe machine can be converted into a magnetic abrasive finishing process. So this process actually it is started from USA okay, but most of the work has been done in USSR so in Soviet Russia okay. Most of the work is done there. After that in Japan many researcher actually contributed into this magnetic abrasive finishing process.

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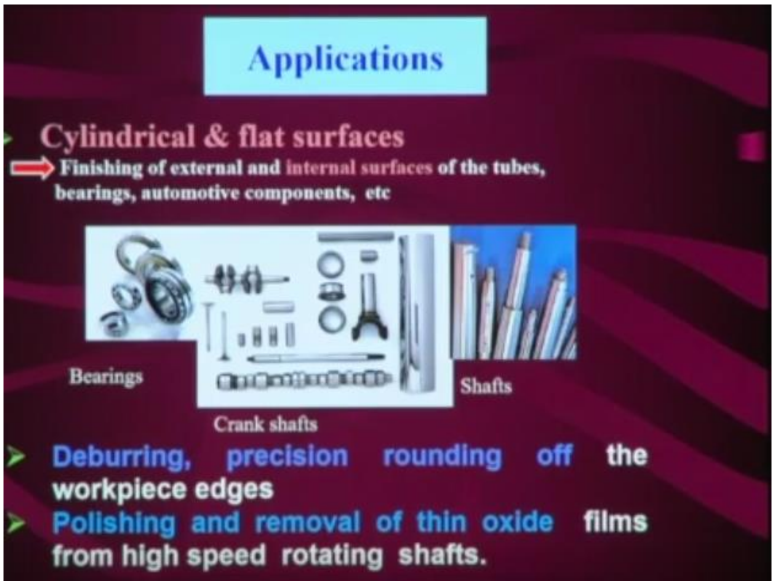

Okay so these are the applications for this magnetic abrasive finishing, cylindrical or flat workpieces can be polished. Finishing of external or internal surface of this tubes, bearings, automotive components like this can be polished. These are the crank shafts, bearings, and shafts. External or internal surface of the shafts can be polished by this forces. Another things are there deburring, precision rounding off the workpiece edges and polishing and removal of the thin oxide films from the high speed rotating shafts can be done by this magnetic abrasive finishing process.

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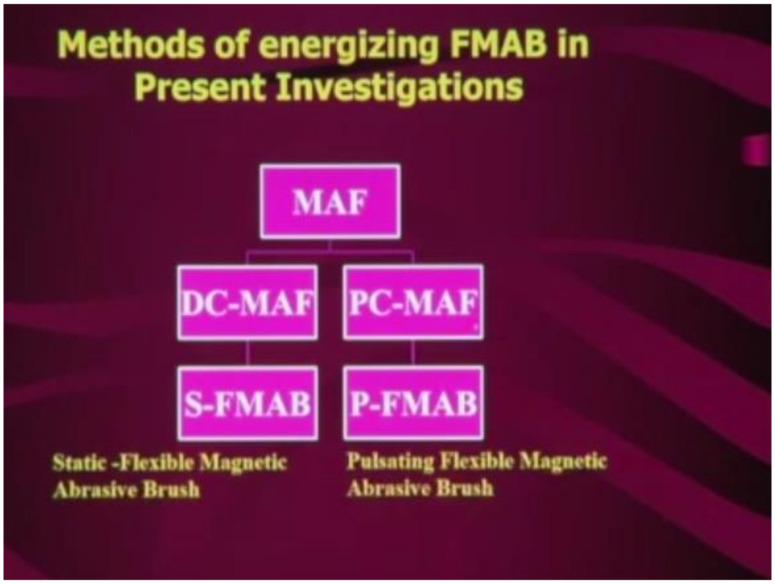

So method of energizing flexible magnetic abrasive finishing in present investigation, there are 2 types of magnetic abrasive finishing; one, in one case constant DC current is used so that is called direct current magnetic abrasive finishing process okay. So there static magnetic abrasive glass is, static flexible magnetic abrasive glass is generated. But another, in another case pulsating current, pulsating DC current are used. So that is called pulsating current magnetic abrasive finishing process, pulsating DC current magnetic abrasive finishing process, or pulsating flexible magnetic abrasive brush.

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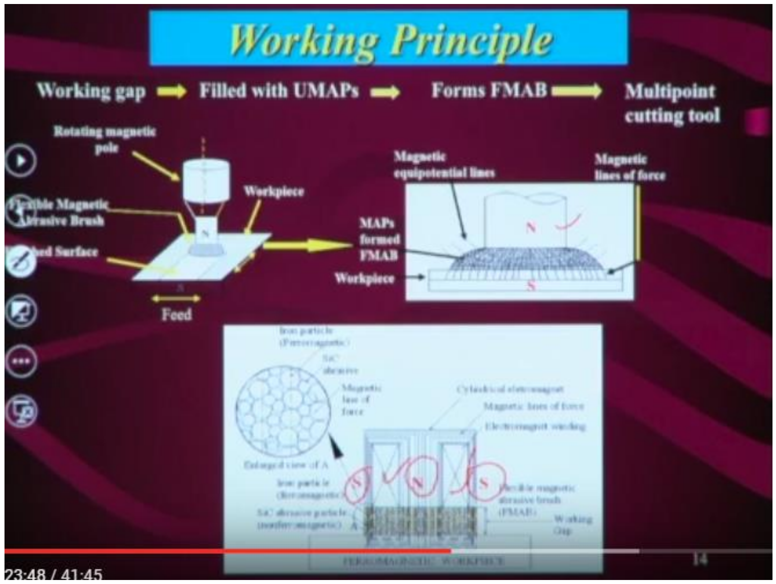

So working principle. So work gap is maintained less than 1 mm field. So this working gap between this magnet and workpiece is filled with abrasive particles forms the flexible magnetic abrasive brush in between this tool and workpiece and multiple cutting tool and multiple cutting tool are used okay. So you can see this one, here this permanent magnet is used or here electromagnet is used in this electromagnet at the center this is the north pole and at the south at the end is the south pole okay. So here this is the coil, 2 coils are used for this kind of magnet.

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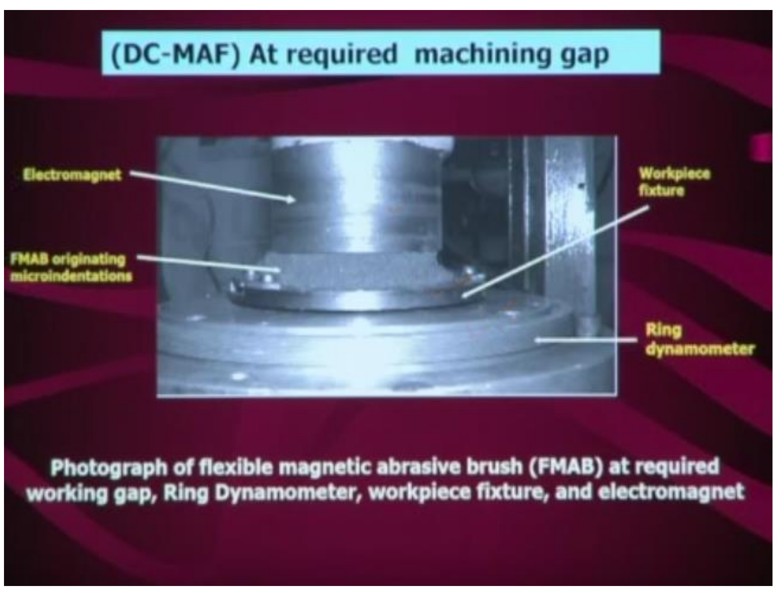

So here you can see this is the magnet here, electromagnet here and this is the workpiece here and in between this workpiece and then electromagnet so this is the workpiece and this is the electromagnet your flexible magnetic abrasive particles are actually kept. So photograph of this flexible magnetic abrasive brush at required working gap ring dynamometer so this is the ring type dynamometer which are used, strain gauge type dynamometer is used for measuring the normal force and tangential force this is the workpiece fixture and electromagnet.

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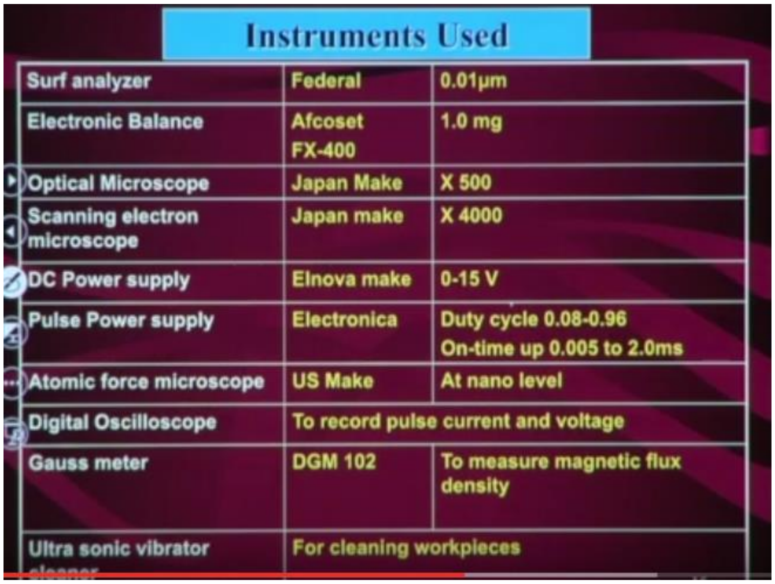

Instruments Used

Surf analyzer	Federal	0.01μm
Electronic Balance	Afcoset FX-400	1.0 mg
Optical Microscope	Japan Make	X 500
Scanning electron microscope	Japan make	X 4000
DC Power supply	Elnova make	0-15 V
Pulse Power supply	Electronica	Duty cycle 0.08-0.96 On-time up 0.005 to 2.0ms
Atomic force microscope	US Make	At nano level
Digital Oscilloscope	To record pulse current and voltage	
Gauss meter	DGM 102	To measure magnetic flux density
Ultra sonic vibrator	For cleaning workpieces	

So these are the instruments used for instruments required for analysis and for the during machining of magnetic abrasive finishing process like surf analyzer is used for measurement of the surface roughness, electronic balance for measuring the initial workpiece width, optical microscope is used for actually for seeing the top surface of this or surface topography of the workpiece, scanning electron microscope and atomic force microscopes are used for seeing the for seeing the surface profile, DC power supply is used for the electromagnet, pulse power supply also used from the for the electromagnet okay. So digital oscilloscope is used to record the pulse current and voltage, gauss meter is used actually to measure the magnetic field in the machining zone, and ultrasonic cleaner is used for cleaning the workpiece.

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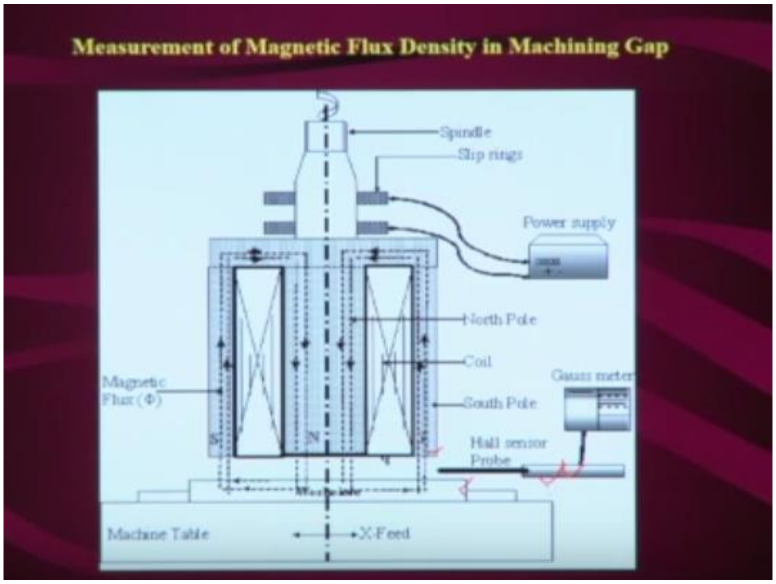

So measurement of magnetic flux density, so here this is the hall probe of this gauss meter, here it is kept in between this tool and the workpiece. So this is the workpiece here, this is the tool here, in between this tool and workpiece this gauss meter is used.

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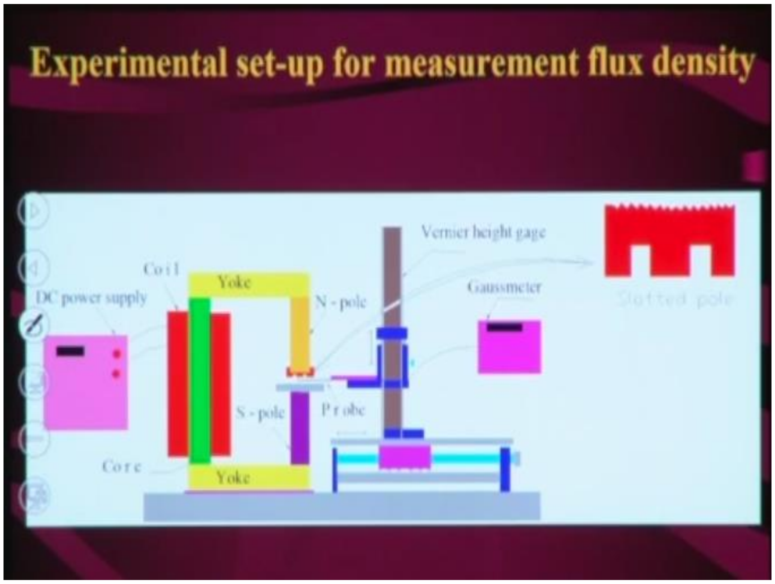

So it is the extracted view or schematic view okay. So this is the hall probe of this gauss meter and these are finishing zone here. It is used for measuring the magnetic field.

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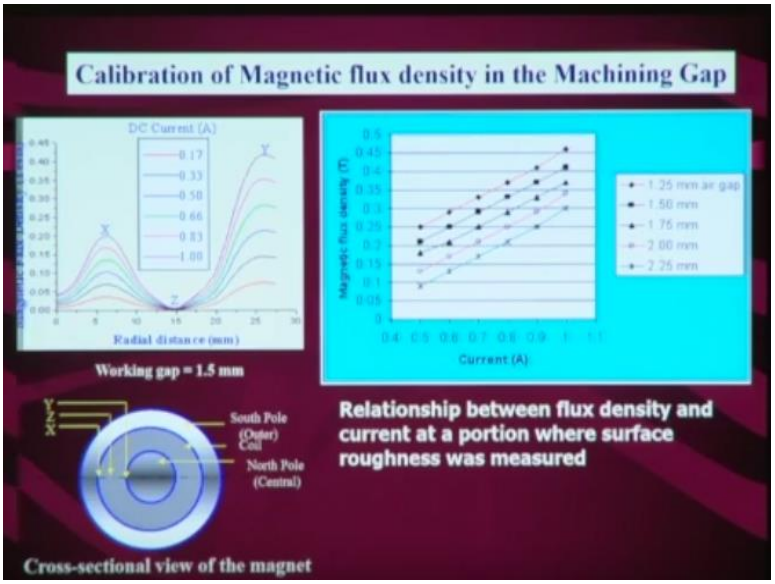

So here you can see with the increase in the current okay from the center to the outer periphery of this electromagnet from the center to the outer periphery of this electromagnet okay how this magnetic field is varying with the increase in the current. So with the lower current you can see here magnetic flux density is less, with the higher current you can see magnetic flux density is more.

So with the current with the increase in current you can see the magnetic flux density is increasing at a certain point here okay. Then with the different gap okay so different magnetic flux density is used. So when your gap is less then magnetic flux density will be high, when gap is more your magnetic flux density will be less.

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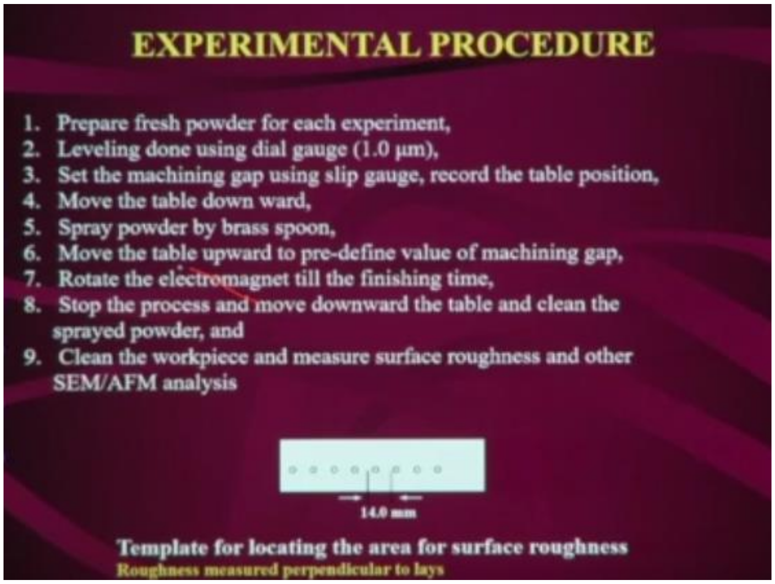

So this is the experimental procedure. Prepare the face powder for the experiment. Leveling is done using a dial gauge, so it is 1 mm gap is maintained. Set the machining gap using a slip gauge, record the table position. Move the table downward.

Spray powder by brass spoon in between this magnet and the workpiece and then move the table toward the pre-defined value of the machining gap. Rotate the electromagnet till the finishing time. Stop the process and move the downward and move the downward the table and clean the sprayed powder and clean the workpiece and measure the surface roughness and surface roughness (()) (27:54) and other SEM and AFM analysis.

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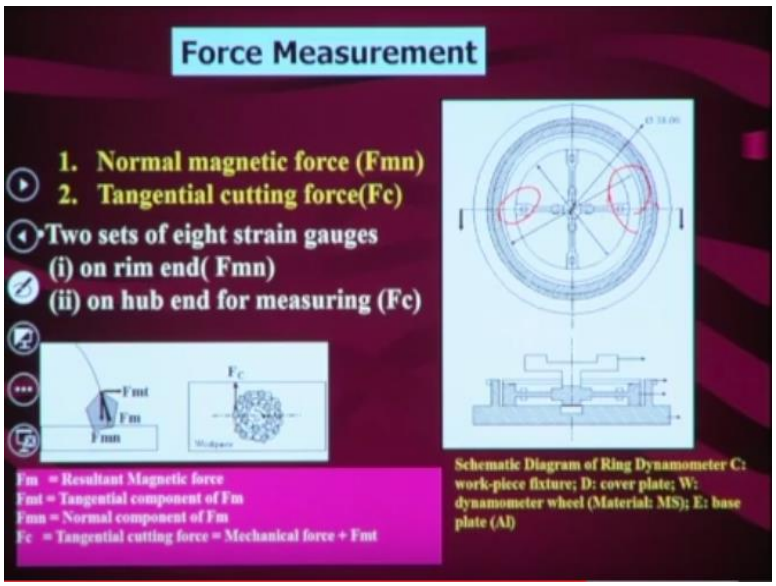

Force measurement. So this force measurement, there are 2 forces are there. One is the normal force, another one is the tangential cutting force. This tangential cutting force is responsible for the cutting operation. So 2 sets of 8 strain gauges, how this strain gauges are helpful okay. So this normal forces this is the ring type strain gauge for the for calculating normal forces so this one and this one, these 2 strain gauges are used. So at the top surface at the bottom surface also another 2 strain gauges are used okay so for calculating the normal force.

And for this tangential force at the side of this rod at the side actually at the side of this rod strain gauges are attached for calculating the tangential forces. So what are the forces are here you can see Fmn is the normal force acting on the workpiece and one only one single abrasive particles is shown and Fmt is the tangential force Fmt is the tangential force which is acting on the abrasive particles.

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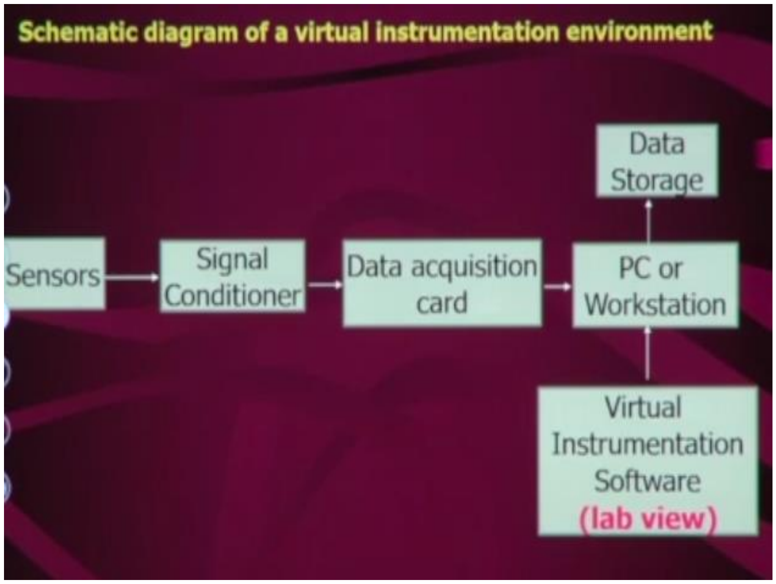

Okay so the sensors, from sensors signal conditioner then data acquisition system PC then data storage and virtual instrumentation software lab view. So from there actually the force is actually measured.

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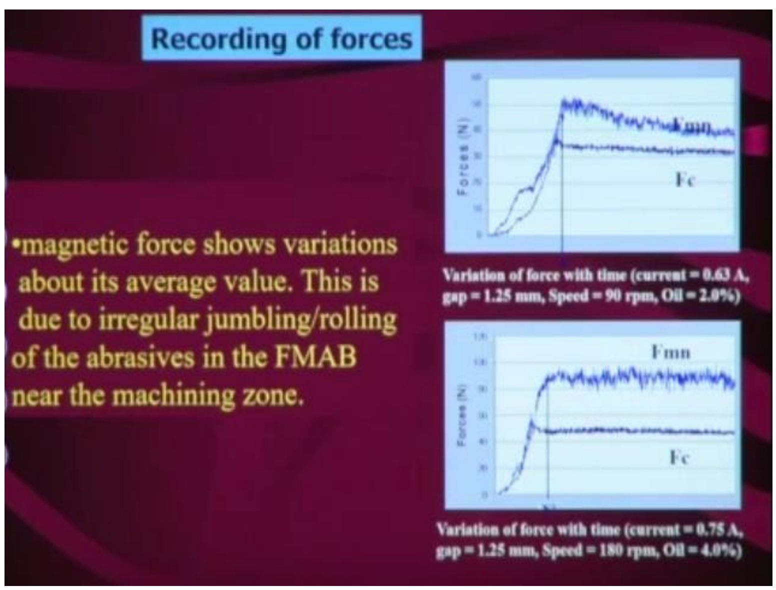

So recording of the forces you can see Fmn, so this is the normal force which is higher than the your cutting force here so normal force is higher than the cutting force here. So it for 0.63 ampere current and for 0.75 ampere current you can see your normal force also increases okay. So it is around 100 but cutting force cutting force it is also increasing for 0.75 tesla magnetic field. So magnetic force shows about its average value and this is due to the irregular jumbling or rolling of the abrasives in the flexible magnetic abrasive brush near the machining zone.

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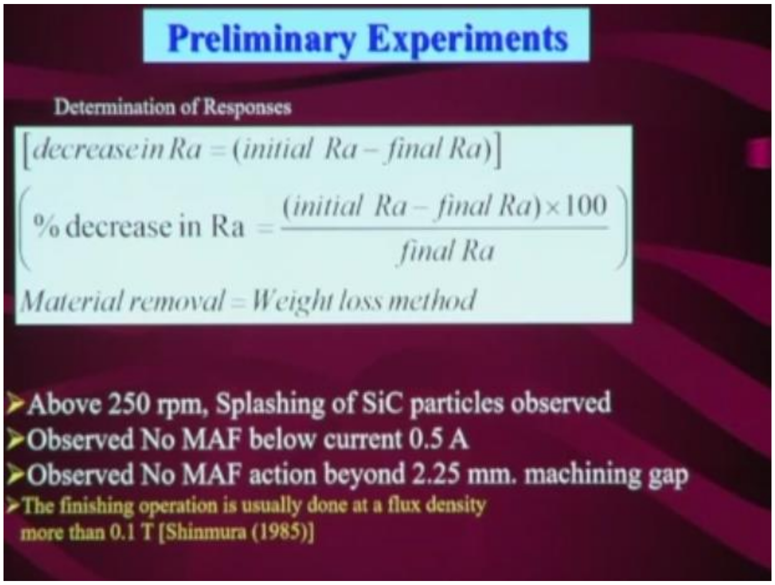

Experimentation using static flexible magnetic abrasive brush. Preliminary experiment, so what are the responses we have calculated? Decrease in Ra initial Ra minus final Ra then personal change in Ra is initial Ra minus final Ra by final Ra surface roughness multiplied by 100 okay so material removal rate so what about weight loss is there which is used as a material removal rate.

So above 250 rpm, splashing of silicon carbide particles are observed above 250 rpm of this magnet and observed number of magnetic abrasive finishing below observed number of magnetic abrasive finishing below current 0.5 ampere. Observed no magnetic abrasive finishing action beyond 2.25 mm okay so beyond 2.25 mm gap so when the gap is more than 2.25 mm okay so there is no magnetic abrasive finishing okay. The finishing operation is usually done at flux density more than 0.1 tesla.

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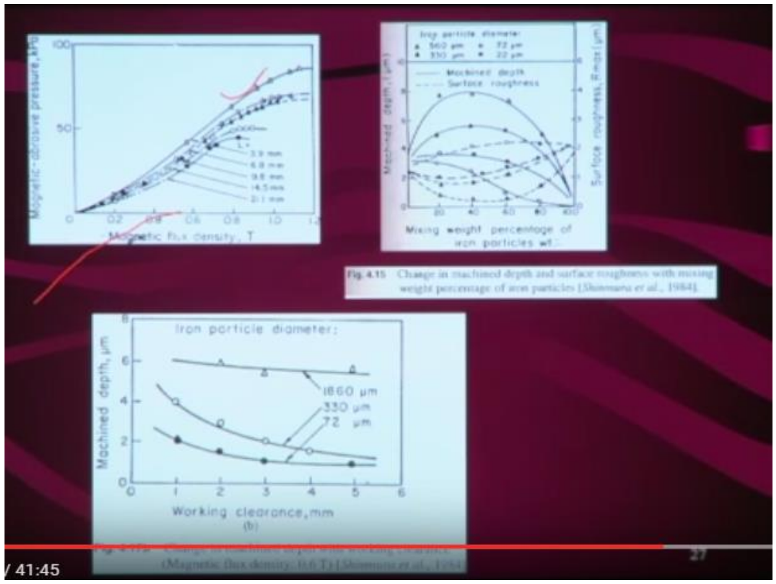

So these are the parametric results for magnetic abrasive finishing process. So this is the with the increase in the magnetic flux density you can see magnetic abrasive pressure also increases okay. So this magnetic abrasive pressure increases with the increase in the magnetic abrasive flux density. Here also you can see mixing (()) (32:00) ratio okay mixing ratio increases with increase in the or machine depth increases with the increase in the machine width parentage of iron particles okay.

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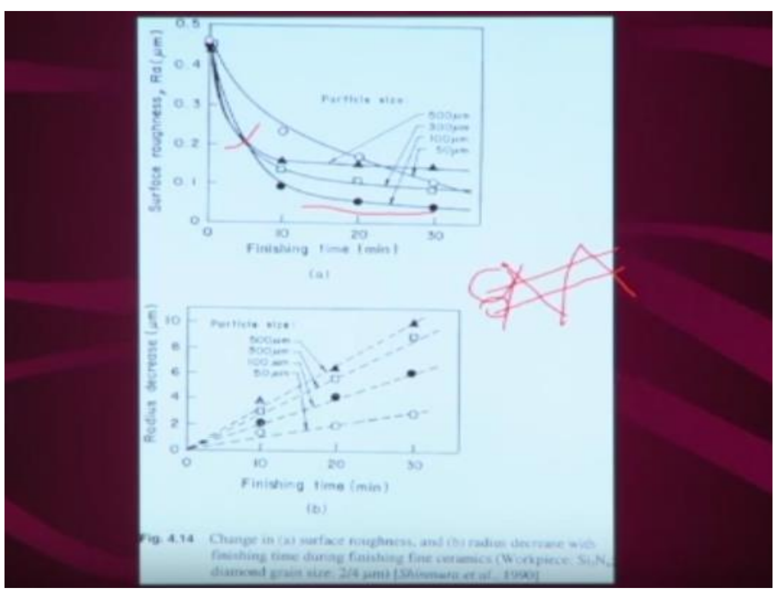

So finishing time you can see that with the increase in the finishing time initially this finishing rate is very high and then after that it is almost actually it is almost stalled here. So what happens actually this surface undulations are actually this kind of triangular shape. When this abrasive particles are actually cutting the surface undulations here after that this shape of this triangular peaks become plateau so it requires actually higher force to cut this plateau bigger size plateau okay so that is why initially this surface roughness actually improves roughness improvement is very high but later actually because of this bigger size plateau this removal rate finishing rate actually it reduces with time. So radius decrease, radius of the workpiece decreases with the finishing time. So radius okay.

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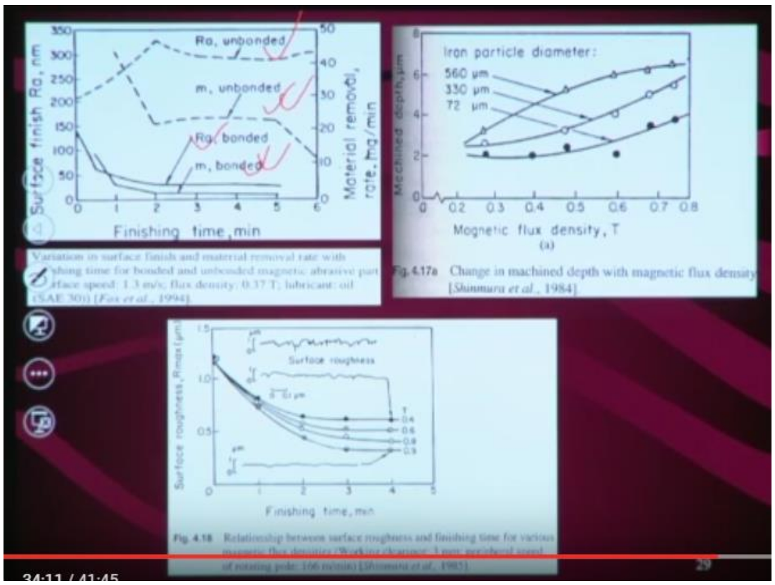

So there are 2 types of abrasive particles we told, one is the unwanted type and another one is the bonded type. So bonded type abrasive particles it gives higher surface finish, but in bonded type abrasive particles their material removal rate is actually less okay. So for bonded type abrasive particles your surface roughness is good, surface finish is good, but their material removal rate is less but in unwanted type abrasive particles their surface roughness is very high but their material removal rate also high okay.

So unwanted type magnetic abrasive particles are used for higher material removal rate and bonded type magnetic abrasive particles are used for getting higher surface finish. So when magnetic flux density is increases then your machine depth also increases okay so if magnetic flux density increases these abrasive particles iron particles are actually will make strong chains and abrasive particles will be held with a higher force. So with the increase in the finishing time you can see here surface roughness also reduces.

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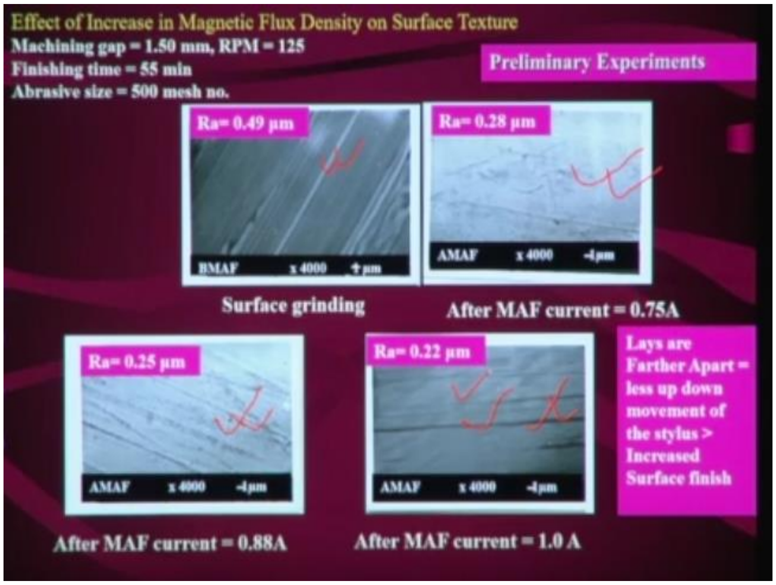

Okay here you can see that usually this surface finish started on the on a grinded workpiece of 0.49 micron workpiece surface roughness okay. So after that flexible magnetic abrasive finishing process is carried out on the same workpiece now surface roughness is reduced to 0.28 micron. Then after that after this magnetic abrasive finishing process for 0.88 ampere magnetic field okay so you can see that surface roughness is further improved up to 0.25 micron okay. So now at 1 ampere current you can see surface roughness is further improved so here it is 0.22 micron. But here all the surface roughness improvements are there but here you can see that this grinding these marks grinding marks are not permanently removed here.

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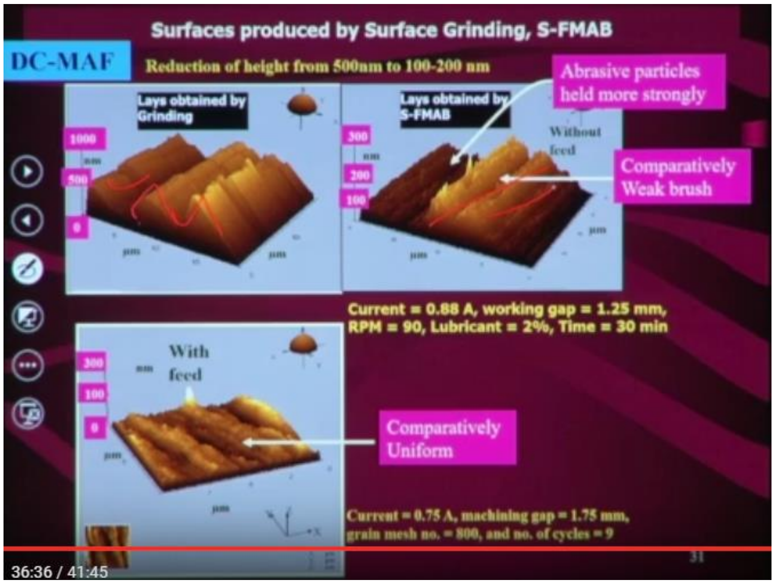

Okay so these are the AFM layers atomic force microscope layers. So I told that this grinded workpiece they have a triangular cross section here you can see this kind of triangular cross section of this grinded workpiece okay so these grinded workpiece when it is polished by static flexible magnetic abrasive finishing process this surface undulations you can see here it is it is removed okay. So now when it is this machining is carried out or finishing is carried out for a longer time you can see this surface () almost removed here okay.

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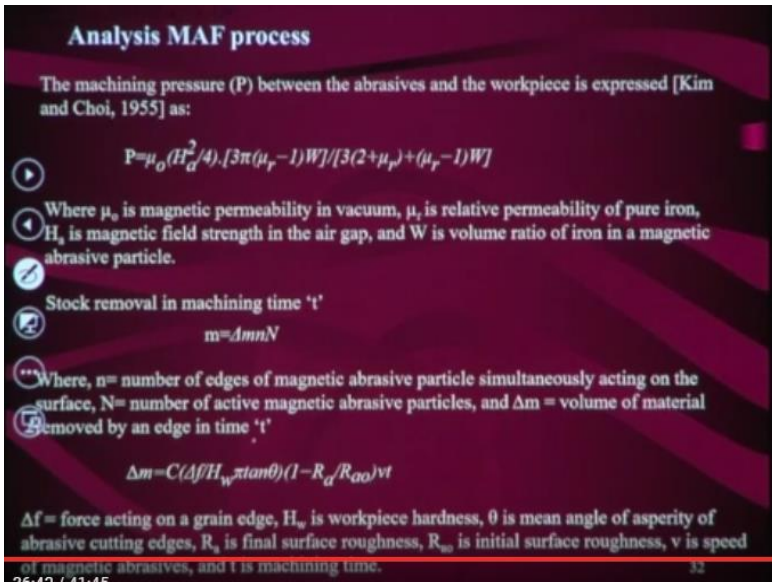

So analysis of magnetic abrasive finishing process. So I told that if you keep this magnetic abrasive particles in between this magnet and the workpiece there is a magnetic pressure actually generated on the workpiece surface. So how to calculate the pressure? So this machining pressure between the abrasive particles and the workpiece machine pressure by the abrasive particles magnetic abrasive particles on the workpiece surface can be calculated as P this is the machine pressure is mu 0 Ha square by 4, 3 by mu r minus 1 into W 1 divided by 3 into 2 plus mu r plus mu r minus 1into W okay.

So here in this case mu 0 is the permeability of air, mu r is the relative permeability of this workpiece material and Ha is the applied magnetic field okay and W is the volume ratio of iron in the magnetic abrasive particles, volume ratio of iron in the magnetic abrasive particles.

Now stock removal can be calculated as m with the time t equal to del m into n into capital N here small n is the number of cutting edges of magnetic abrasive particles simultaneously acting on the surface. Capital N is the number of active magnetic abrasive particles, number of active magnetic abrasive particles and volume of material removed by an edge in time t is calculated as del f by Hw pi tan theta into 1 minus Ra by R0 into v into t. So del f is the force acting on a grain edge, Hw is the workpiece hardness and theta is the mean angle of asperity of the abrasive cutting edge and Ra is the final surface roughness and Ra is 0 is the initial surface roughness and v is the speed of magnetic abrasive particles and it is t is the machining time.

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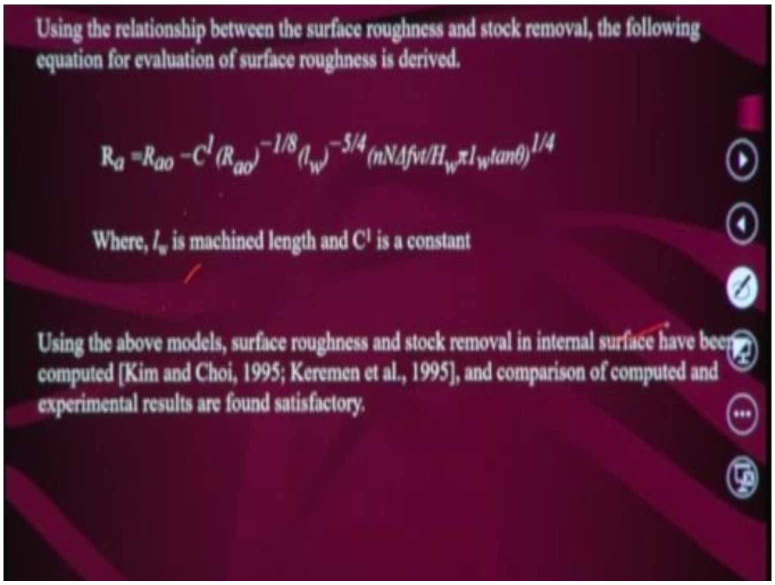

So here after putting all these values okay so we can get the final surface roughness in terms of this initial surface roughness C1 is the constant here and then lw is the machine length and C1 is the constant. So using this above models, surface roughness and stock removal in internal surface have been computed and comparison of computed and experimental results are found satisfactory.

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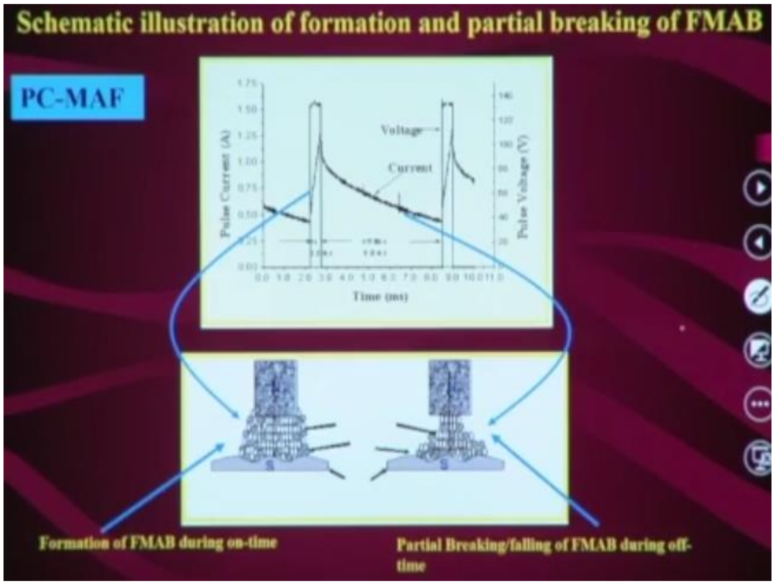

So experimentation using pulsating current flexible abrasive magnetic abrasive brush. So you can see here so here current actually so this kind of pulsating current we are using okay. So this pulsating currents are actually helpful for proper mixing of this abrasive and iron particles. So it helps in proper mixing of this abrasive particles and iron particles.

Otherwise whatever abrasive particles are there at the external periphery okay so it will be the same abrasive particles will be there, there will not be any change okay. So for machining to take place we need more active abrasive particles which are taking part into the polishing action.

So that is why if we use flexible magnetic abrasive brush so as the current actually it is reducing and then it is jumping again it is reducing it is jumping again okay so during this off time of this pulse okay so there is chances that this magnetic and abrasive particles okay it will properly homogeneously mix and during on time it will do the polishing action. So in this way we can increase the machining efficiency of this flexible magnetic abrasive finishing process.

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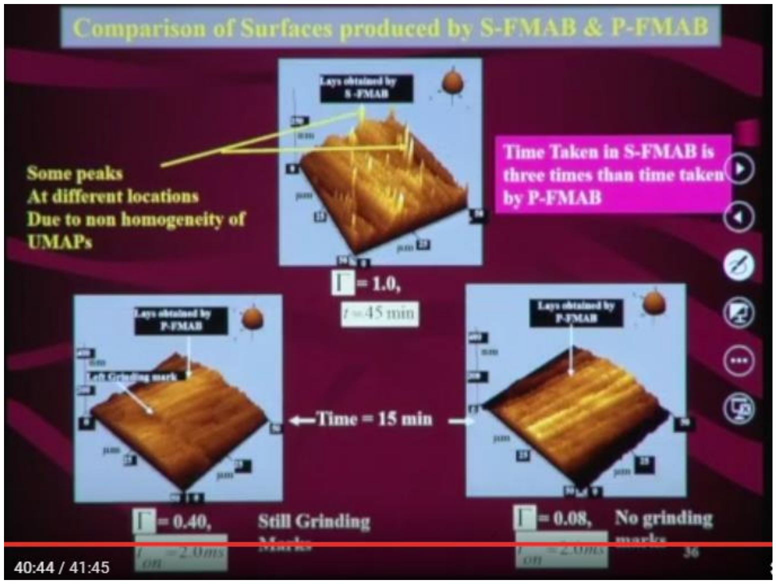

So comparison of surface produced by static flexible magnetic abrasive finishing and pulsating current abrasive finishing process. So here some peaks are actually available at different location due to the non-homogeneity of abrasive magnetic abrasive particles okay, unwanted magnetic abrasive particles. So time taken in static flexible magnetic abrasive brush is 3 times than the time taken by pulsating current flexible magnetic abrasive brush.

So here we can see steel grinding marks are actually visible okay. So by using this static magnetic abrasive brush but here this this is done this is done actually by using this pulsating current magnetic abrasive brush. Here you can see this bending brush almost done okay. So you can expect better surface finish by this pulsating and magnetic abrasive finishing process okay.

Thank you.