Manufacturing Processes - 1

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Module - 1
Lecture - 12
High Energy Rate Forming Processes

A warm welcome to all of you. Today, we are going to start our discussion on High Energy Rate Forming processes. Before we initiate our discussion on this topic of High Energy Rate Forming, we will just have a review of what we have discussed till now. In this series of lectures on Manufacturing Technology, we started our discussion with an important aspect of Manufacturing Technology that is Powder Metallurgy. In powder metallurgy, we had a series of lectures - we had three lectures on powder metallurgy - in which, we discussed, that what is the basic powder metallurgy mechanism? What are the various types of metal production techniques? Then, we discussed how the sintering takes place. What is hot isostatic pressing? What is cold isostatic pressing? Then, we went on to discuss the various stages of powder metallurgy, coming on to the final and the finishing operations like impregnation, infiltration, forging, machining, and all the important aspects of powder metallurgy were covered in the three lectures on powder metallurgy.

Thereby we switched our attention on metal forming processes. In metal forming processes, we discussed, that what is the basic principle of metal forming? What is plastic deformation? How does plastic deformation takes place in metals? What are the slip planes? How the slip planes enhance the process of plastic deformation.

Then, we have discussed what are the different metal working conditions, like we discussed cold working, hot working, warm working. In cold, hot, and warm working, we discussed what are the advantages and disadvantages of this processes; where to use cold working; where to use hot working - all those things were discussed in Basics of Metal Working Principles.

Then we discussed that what are the various types of metal working technologies or metal working operations. Thereby we discussed - What is forging? What are different types of forging operations? We discussed swaging; then we discussed other metal working operations like tube drawing, bending, deep drawing. And then, we went on to discuss sheet metal operations. Like in sheet metal operations we discussed - what is shearing? How does shearing takes place? Then different types of operations like nibbling, notching, blanking, punching.

Thereby we went on to discuss the important aspects of the Die and Punch Arrangement; different types of mechanism; different types of dies, in which we discussed that there is a conventional type of die punch arrangement, then there is an inverted die, there is a compound die, then there is a progressive die. Thereby we discussed how blanking and punching, shearing can be done with the help of die and punch type of arrangements.

Now, today, we start our discussion with other important aspect of manufacturing technology that comes into the picture when some special characteristics have to be imparted or we need to make certain special type of products. So, today we will initiate our discussion regarding High Energy Rate Forming Processes. First of all, we will see why they are called high energy rate forming processes and what is the need to go for high energy rate forming processes.

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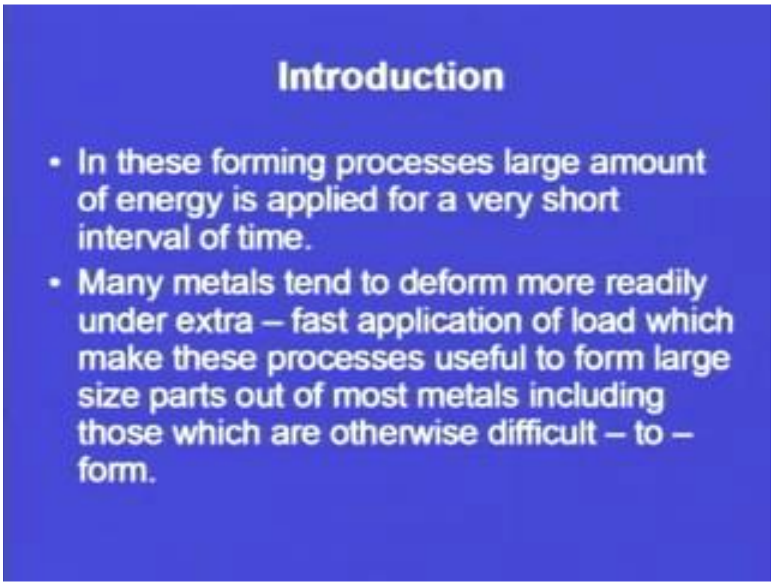

Now, coming on to the introduction of this topic. In these forming processes, large amount of energy is applied for a very short interval of time. So, the first point states that there are two important aspects of high energy rate forming: First one is a large amount of energy and for a very small interval of time. In case of deep drawing - if you take the example - we are using a punch and a die type of arrangement, and the punch goes into the die, and in between is the sheet metal, which we want to deform.

So, the process is not sudden; it is not impact loading. If we give impact loading, then there are chances that the sheet metal may fail, the cracks may appear, some micro cracks may appear, and that may further result into a catastrophic failure; but here in case of high energy rate forming processes, they give a very high energy and for a very brief interval of time or for a very small interval of time, in order to plastically deform the sheet metal to give it the desired shape. In the subsequent part of this lecture, we will see what are the different types of processes that are incorporated into high energy forming processes.

Then, many metals tend to deform more readily under extra fast application of load. Extra fast means that the time interval is very, very small, which make these processes useful to form large size parts. So, another important aspect here is that we are going to make large size part or the versatility of these processes lies in making large parts out of most metals including those which are otherwise difficult to form.

So, these two points basically gives us an overview that what is the application spectrum; what is the application area of high energy rate forming processes. So, what is the application area? So, there are some important points - that high energy is applied for a very brief interval of time; can be used for difficult to form materials; and another application or another important aspect is that the size of the part is not a limitation, even if the size of the part is bigger one, we can use these processes. So, many metals have this tendency, that they deform under extra load or extra high load exerted for a very brief interval of time. So, for those metals also these types of processes can be used.

Now, before we start, we have already been discussing number of manufacturing processes. Initially, when we initiated the discussion on manufacturing processes or the processes that we have discussed in these series of lectures, we started our discussion that there is always an option for us or for any engineer to choose that which process should be selected for which particular shape, which particular size, which particular material. So, before we go for the selection of a process, a number of variables, and a number of parameters have to be studied, and then we make a trade off. So, what helps us during that trade off are the advantages and the limitations of that particular process.

For example, we take example of casting. So, within casting also there are number of casting processes like sand casting, then there is pressure die casting, there is die casting, hot chamber die casting, cold chamber die casting, slush casting - different types of casting processes are there.

Suppose we identify that this product has to be made out of the casting process. Thereby, we have to decide which casting process should be used for this particular shape, this particular size, and this particular accuracy, this particular tolerance level. So, how do we come on to the selection of a particular process or a particular requirement? It is only possible if we know the advantages and limitation of that particular process. If we are not knowing the advantages and limitations, then it becomes difficult to identify or to classify or to select a particular process for a particular application.

Similarly, coming to our present discussion, we are discussing high energy rate forming processes. We have seen what are high energy rate forming processes - a high energy for a very brief interval of time; where is the application spectrum - that are also we have seen. So, these processes have certain advantages and limitations over the normal processes or the normal forming processes, which made them advantageous over the normal forming processes, but on the contrary, there are certain limitations also.

So, these advantages and limitations have to be studied before we go and choose a high energy rate forming process to convert our raw sheet of metal into our final product. So, what are these advantages and limitations? That we will just see.

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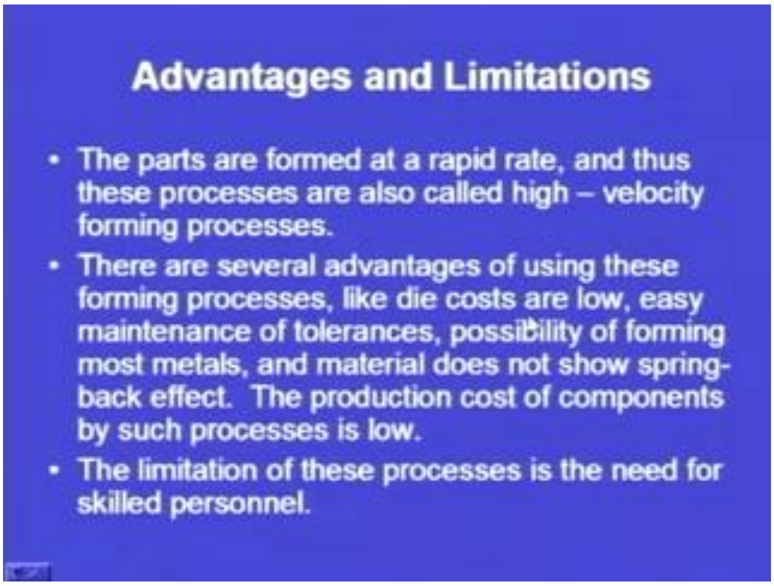

The parts are formed at a rapid phase So, the production rate or the production volume in case of high energy rate forming processes is more as compared to the normal processes. So, the parts are formed at a rapid rate and thus these processes are also called high velocity forming processes. So, I have already told the process is not slow, it is a very fast process. So, the parts are formed at a very rapid rate. So the production rate is very, very high. There are several advantages of using these forming processes, like now, there are several other advantages. First one is the production rate is high, because these are also called high velocity forming processes.

Then the other advantages are the die costs are low. So, the die that we are using; yesterday we saw what are the different die manufacturing methods; in the previous lecture, we have seen what are the die failure techniques or die failure mechanism - how the die fails; so all those were seen. So, die costs are low here, because if the die costs are low, then, even if the die fails, even if a catastrophic failure takes place or the die has not been properly designed or there is some material problem selection - so, we have seen that if there is some problem in the material selection, then also the die may fail. So, the die costs are relatively low in these processes; if there is some problem with the die, then it can be replaced at a very low cost. So, die costs are low in case of these processes. Easy maintenance of tolerances. So, the tolerances can be very easily maintained in case of these processes.

Possibility of forming most metals. So, the versatility of these processes lies in the forming different types of metals. So, we have seen earlier also the different types of metals can be formed using high energy rate forming processes, and the material does not show spring back effect. So, specifically, when we were discussing the bending operation, we have seen that there is a chances of spring back. So, if there is a straight sheet, and we want to bend it like this at a particular angle, there are chances that after we release the force that we have applied, there are chances that it will spring back to a different angle. So, that kind of effects are not possible with these type of high energy rate forming processes.

So, the production volume of components by such processes is low. So, the production cost; the production cost of components by such processes is low; we are not talking about the production volume, we are talking about the production cost. So, the cost is also low; the volume is comparatively high.

So, just we have a brief review that what are the advantages of these processes over normal forming processes. We will see that there are several advantages of using these forming processes like die costs are low; easy maintenance of tolerances; possibility of forming most metals - that is one versatility of this process; and material does not show spring back effect - so, there is no spring back effect in case of high-energy rate forming processes.

The production cost of components by such processes is low - so, the processes are economically justifiable or economically justified. Whenever we want to make a particular product, we have to economically justify that if we use this process, by this process, we will be able to make this much number of parts in this much time. So, we have to calculate what is going to be the costing of that particular material that we want to sell in the market. So, if the process is economically justified, then only we will go and select that process; otherwise, there is no point in selecting a costly process which converts the raw material into the final parts at a relatively high cost; but the advantage of you choosing high energy rate forming processes is that the production cost will not be that much.

Then as I have already said, it is not the advantages only which are important to us; these are the limitations also which are equally important.

So, the limitation of these processes is the need for skilled personnel. So, as we have seen that in normal forming processes like bending and all, we need not have a very skilled personnel; semi skilled labor can perform the operations like stamping, punching blanking; but here in case of high energy rate forming processes, skilled labor is the pre-requirement. So, it is a pre-requisite - if we have a skilled labor, then only we will be able to operate these kind of machines or these kind of setups, which have the basic principle of high energy rate forming.

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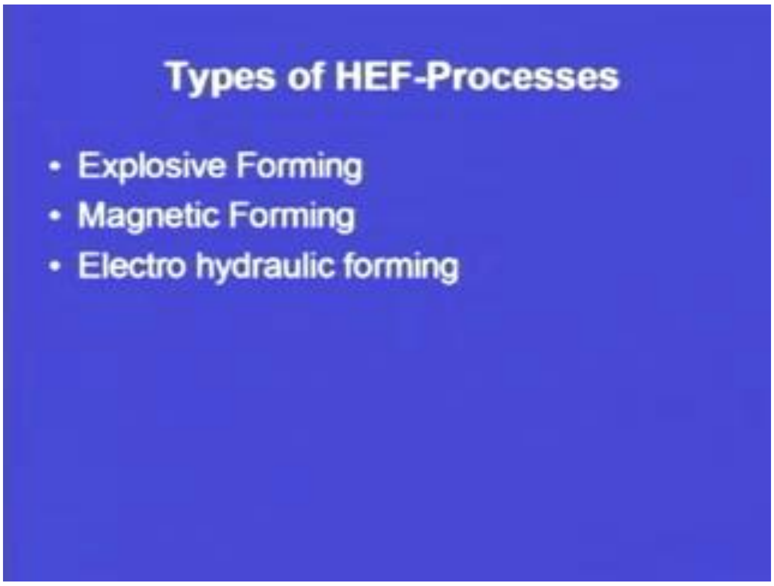

Now, coming on to the classification of high energy rate forming processes. These can be classified on the basis of their basic mechanism of sheet forming. So, these we can have explosive forming; then, we can have magnetic forming; then, we can have electro hydraulic forming. So, depending up on the mechanism or depending up on the technique that we are applying, we can classify the type of processes HEF processes - as you can see on your screen - HEF means high energy rate forming processes.

So, in explosive forming, we make use of an explosive. In magnetic forming an electric current high voltage is supplied which helps us to convert the raw material into the final product. And in electro hydraulic forming there is a combination of electric and the shock waves are produced; these shock waves then convert the raw sheet metal into its final product. So, we can have a constrained die or it can be a open type of unrestrained forming can also be done.

Now, in the subsequent part of this lecture, we will discuss each of these processes in detail. We will see with the help of diagrams, that how the particular process takes place; what the particular advantages of that particular process are; for what type of materials that process can be used.

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So, we start our discussion with explosive forming. So, explosive forming, as you can see on your screens, is distinguished from the conventional forming in that the punch or diaphragm is replaced by a explosive charge.

So, in the very first point, it has been addressed that how explosive forming is different from the conventional forming. In conventional forming there is a punch or a diaphragm, and then, there is a die, which is used to convert the raw sheet into the final sheet; but in case of explosive forming, that punch type of arrangement is not there; it is replaced by an explosive charge. So, the explosives used are generally high explosive chemicals. So, we are not going into the details that what type of explosives are used, but we are just going to see that what are the basic formations of those chemicals, like these are some explosive chemicals can be used; gaseous mixtures can be used as explosives; or some kind of propellants can be used.

So, we are just going into the family of the explosives; we are not going into the details of the families. So, the explosives used are generally high explosive chemicals, gaseous mixtures, or propellants. There are two techniques of high explosive forming: first one is the standoff technique and the contact technique.

So, we have seen in this particular slide that explosive forming is a process which has replaced in some particular application spectrum the conventional forming processes. The punch type of arrangement is absent in case of explosive forming, and we make use of a explosive charge which is used to change the shape of the sheet. Then, different types of explosives are, these can be some explosive chemicals, some gaseous mixtures, or these can be propellants. So depending up on the requirement we will choose our explosive.

Then another point that has been addressed in this slide is, that there are two types of explosive forming processes: the first one is the standoff technique and the second one is the contact technique. So, now we will move on to these two particular techniques that - what are the basic mechanisms of these techniques?

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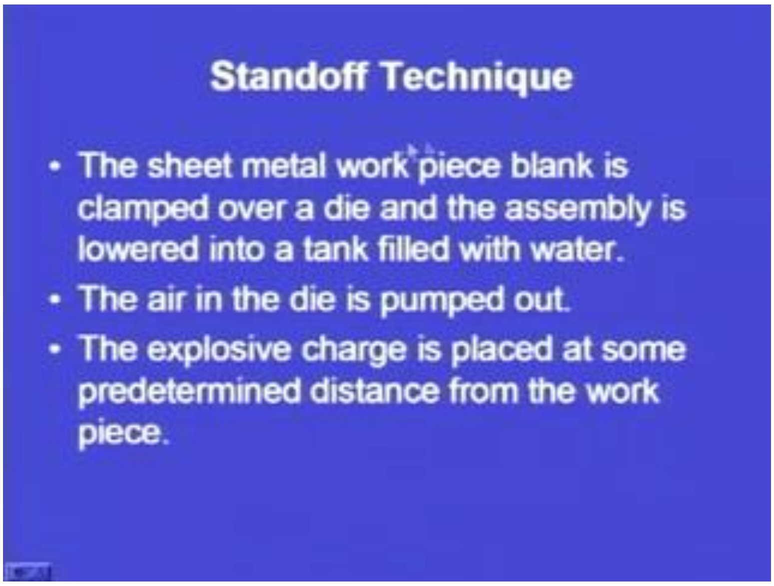

Now, first we will discuss the standoff technique. In case of standoff technique, the sheet metal work piece blank is clamped over a die. So, here the die arrangement is there, because the die will directly create a cavity of the shape that we want to produce. So, if a sheet metal, we want to give a particular shape, the die will have the exact replication of that sheet. So, the sheet metal work piece. So, this process we are going to use for converting the shape of the sheet metal. The sheet metal work piece blank is clamped over a die.

So, there is a die over which the sheet metal is clamped, and this is the work piece. And the assembly is lowered into a tank filled with water. So, we have a die; on top of it we place our sheet metal - that is our raw material that we want to convert it into a final product; and this assembly is then lowered into a water tank. The air in the die is pumped out. So, there is no air that is left inside the die, that is pumped out.

The explosive charge is placed at some predetermined distance from the work piece. So, this is one important point that should be noted. The explosive charge - as we have already seen in explosive forming, we will be making use of a explosive charge. The explosive charge is placed at some predetermined distance. So, suppose this is the die cavity, on top of this we place our sheet metal that we want to deform - that we want to plastically deform - and the explosive charge is kept at a distance. So, there is some distance between the explosive charge, and the die and the sheet. And this die and the sheet is pressed inside the or is immersed inside the water tank. In between the sheet and the die the air is taken out. So, the explosive charge is placed at some predetermined distance from the work piece. So, work piece - what is the work piece in our case? The work piece in our case is the sheet metal. So, the charge is at a distance.

So, now on detonation of the explosive. Now this explosive which can be, we have already seen it can be some form of explosive chemicals, it can be gaseous mixture, or it can be any kind of propellant; that charge - that explosive charge - on detonation of the explosive, a pressure pulse of very high intensity is produced - a pressure pulse will be produced and the intensity will be very, very high. So, if the intensity is not high, then it will become extremely difficult to change the shape of the sheet metal. So, a pressure pulse of very high intensity is produced on detonating the explosive.

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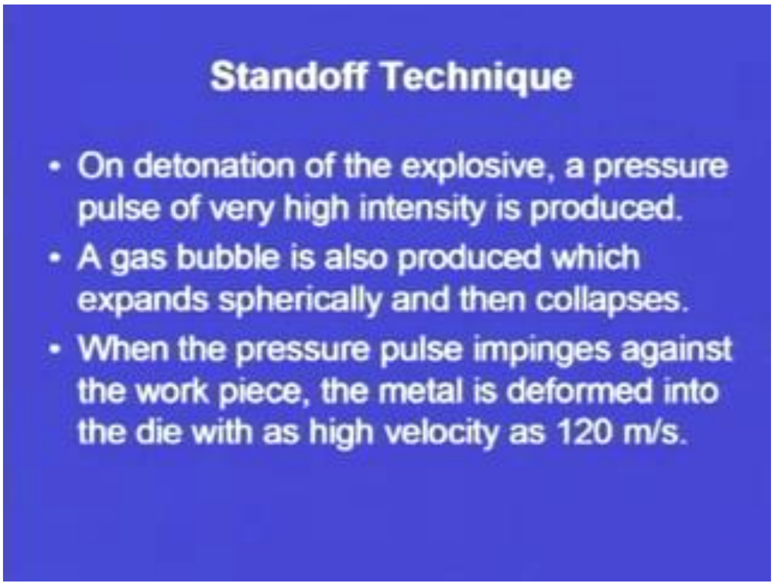

A gas bubble is also produced which expands spherically and then collapses. So, this we will try to understand with the help of a diagram. When the pressure pulse impinges against the work piece - now there is a work piece; there is a pressure pulse that has been created by the detonation of the explosive. When this pressure pulse will come down and it will impinge against the work piece, the metal of the work piece or the work piece is deformed into the die with as high velocity as 120 meter per second.

So, a rule of thumb or some particular value has been quoted - that is 120 meter per second. So, we can see that the explosive is detonated; there is a pressure pulse that is created; that pressure pulse impinges against the work piece; and the metal is then deformed at a very high velocity - that velocity may be to the tune of 120 meter per second.

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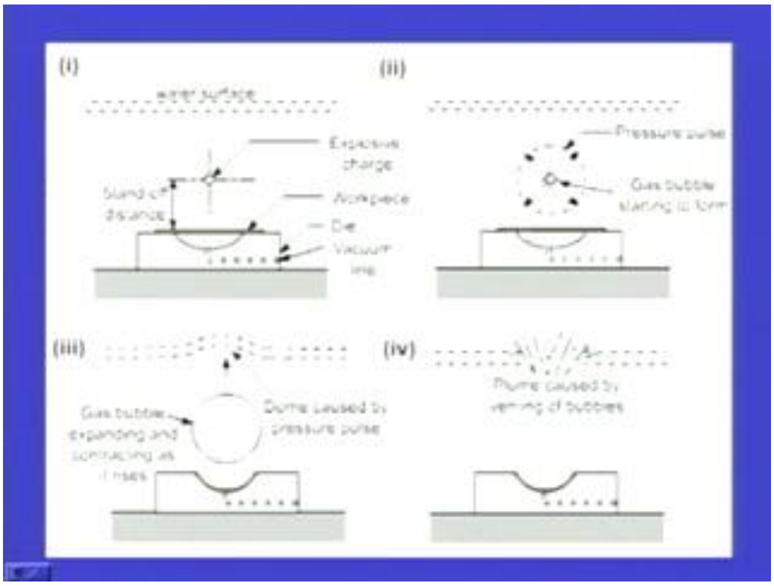

So, we can see, this is the diagram on your screen now. Whatever we have discussed, this is a diagram that explains whatever has been discussed till now. So, this we can see, just to understand what is the labeling of the diagram. First, one is the die; you can see this is the die; this is the vacuum line. So, why vacuum line is required? It is required in order to suck the earth. We have seen that there should be no air inside the die cavity. So, we may use a vacuum line or we may suck it by some other mechanisms. So, there should be no air inside the die cavity; it has to be removed.

Then, this is a die. There is a vacuum line. Then, this is the work piece. The arrow depicts - this solid portion of a different color, this solid portion, see the arrow moving on the screen - this is the work piece of the sheet metal. Then, there is an explosive charge; this is the explosive charge. And this is the standoff distance; there is a distance between the work piece and the explosive.

So, and another important point to note here is that this is the water surface. As we have already discussed, the die and sheet metal is immersed in a tank of water. So, this all assembly, whatever we are seeing here is under a water surface; this is being done under the water.

So, we come on to the second; the detonation has taken place and this is a pressure pulse that has been generated. After the pressure pulse has been generated, this pressure pulse goes and impinges against the sheet metal. Also we have seen that a gas bubble starting to form; in the initial transparency or the slide, we have seen that this gas bubble also that forms inside the pressure pulse. So, this is the gas bubble, this particular area; gas bubble starting to form and this is the pressure pulse total; this is moving in this direction.

Now, we see that the gas bubble expanding and contracting as it rises. So, gas bubble is contracting and expanding, and the dome caused by the pressure pulse. See, this is the water surface; this is the water surface plane here; then this is a dome that has been caused by the pressure pulse; and you can see that the pressure pulse has here deformed the sheet metal. Till now - till second stage - a deformation has not taken place, but a pressure pulse has been generated on detonation of the explosive, after this pressure pulse impinges against the sheet metal it deforms the sheet metal like this. In the meanwhile, the gas bubble expands and contracts as it rises.

Then coming on to this particular section, we see that the work piece that we want to get has been made and the dome caused by the venting of bubbles, on this water surface we will see that there will be some bubbles coming out like this, venting of bubbles will take place. So, there are four steps that have been explained in this particular diagram.

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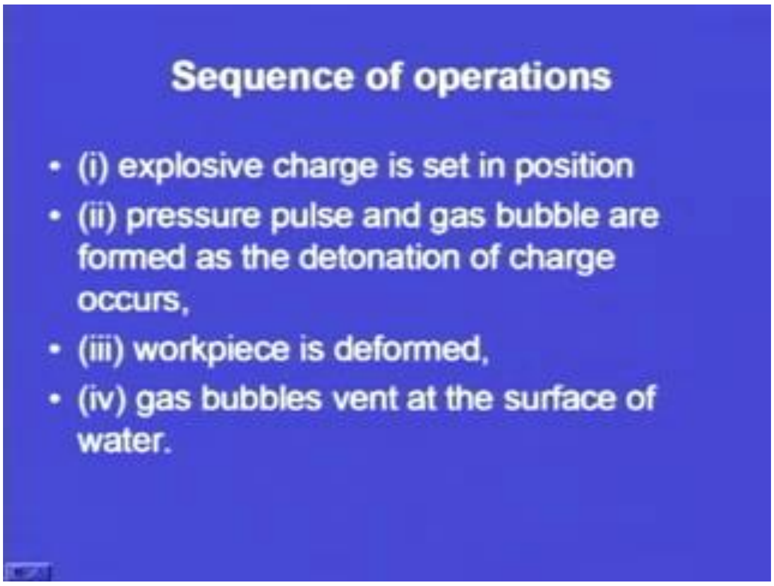

Now, these sequence of operations that we have discussed there are 1, 2, 3 and 4 operation. Just to explain these operations, just to summarize this operation, just to understand them in a better possible manner: the first is the explosive charge is set in position; when we have die and the sheet metal has been placed under water, then we set the explosive at a standoff distance from the sheet metal. So, the explosive charge is set in a position. Pressure pulse and gas bubble are formed as the detonation of charge occurs. So when the explosive charge has been placed at a standoff distance, and as soon as it detonates, a pressure pulse is generated, and a gas bubble is generated in between.

So, this is the standoff distance. The explosive charge has been placed at a distance, and then, when it is exploded, a pressure pulse is generated. A pressure pulse and gas bubble are formed, as the detonation of the charge occurs. Then the work piece is deformed. We have seen that the work piece was straight under the impingement of the pressure pulse, it deforms. Then, the gas bubbles vent as the surface of the water. So, the gas bubbles then vent out at the surface of the water.

So, this is the very basic principle of explosive forming - the punch is not used; whatever deformation of the sheet metal is taking place, it is taking place under the impingement of the pressure pulse that has been created in the water using the explosives. So, explosive can be of any type which has already been discussed.

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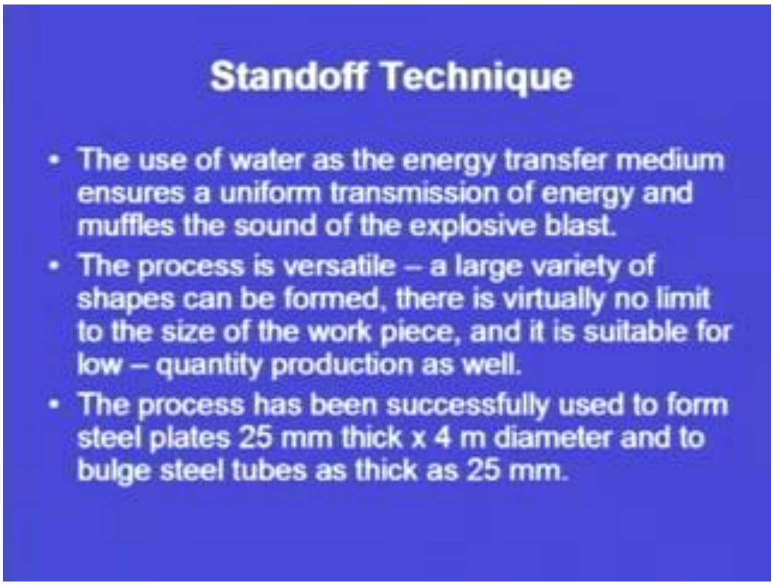

Now, in case of standoff technique that we are discussing, as a sub category of explosive forming process, the use of water as the energy transfer medium. So, another question can be - why are we placing our assembly, whatever performance we are doing, or whatever operation, we are doing we are doing it under water only? Why is that? What is the need of doing it under water? The use of water as the energy transfer medium ensured the uniform transmission of energy. So, we have seen a pressure pulse that has generated a uniform transformation of energy is ensured if we are doing it under water. Use of water as the energy transfer medium ensures the uniform transmission of energy, and muffles the sound of the explosive blast. So, if we are doing it under water, there will not be a sound explosion or there would not be a sound or we can say that pollution because of sound may not be there. So, the use of water, we can see, that it has certain advantages. If we do it in air, there are certain disadvantages; in order to overcome those disadvantages or in order to overcome those limitations, we are doing the process under water.

So, there are two basic advantages - these two basic advantages are: uniform transmission of energy and it muffles the sound of the explosive blast. So, because of these two advantageous conditions that are possible when we perform the operation under water, we choose to do it under water.

The process is versatile. Already in the brief description of these processes - these three processes, that we will be discussing in today’s lecture - these processes are very versatile processes. So, if we talk about explosive forming in particular, this is also very versatile process.

A large variety of shapes can be formed. So, we can see the shape depends up on the shape of the die. So, whatever is the shape of the die, we can create, we can generate a shape on the sheet metal. So, large variety of shapes can be formed. There is virtually no limit to the size of the work piece. Already we have seen that size is no limitation in high energy rate forming processes. So, we can make size, big shapes - big sizes and big shapes – also.

And it is suitable for low quantity production as well. So, most of the times we see that always we say that the production rate should be high, the volume of production should be high in order to justify the cost of the infrastructure or the cost of the machine, but here, this can be used for low quantity production as well.

So, the three basic advantages that we have seen in case of standoff technique are that: it can be used for a large variety of shapes; the size is no limitation; and then, it is suitable for low quantity. So, the volume size and shape, in case of standoff technique of explosive forming are no limitations. So, the process is versatile; a large variety of shapes can be formed; there is virtually no limit to the size of the work piece; and it is suitable for low quantity production as well. So, this is the brief summarization that we have discussed.

The process has been successfully used to form steel plates 25 millimeter thick and 4 millimeter in diameter and to bulge steel tubes as thick as 25 millimeters.

So, this standoff technique we have seen, it is an explosive forming technique. In explosive forming, we can either deform a sheet or we can deform a tube. So, it gives a one particular example that this process of standoff technique in explosive forming has been used to form steel plates those are 25 millimeter thick and 4 millimeter in diameter and this can also be used to bulge steel tubes. So, bulging steel tube means, if a tube is like this, we are going to create a bulge at any particular cross section and as thick as 25 millimeter. So, this can be a, this is a versatile process; the shape is also no limitation for this; the size is no limitation. Moreover, another important point is that low quantity production is also possible using the explosive forming technique.

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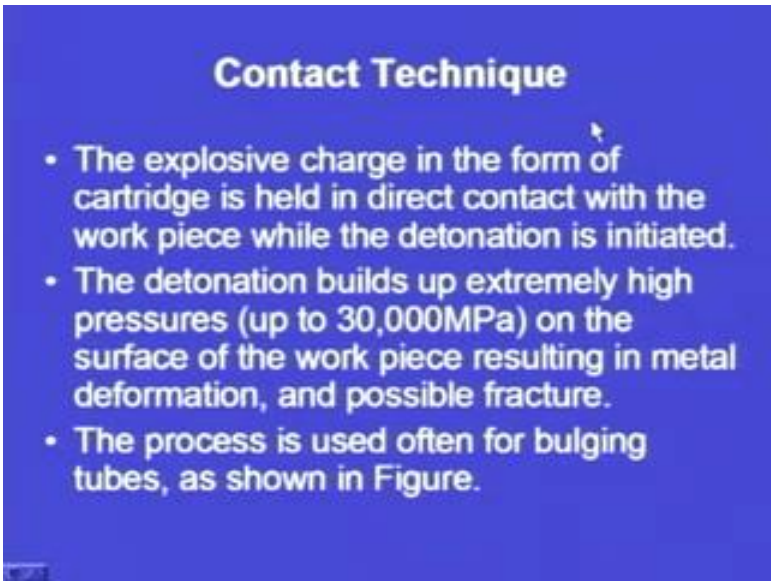

Now, coming on to the explosive charge in the form of… coming on to the contact technique. So, we have been discussing that what is the explosive forming. In explosive forming, we discussed what the standoff technique is. So, there are two different types of techniques in explosive forming - first one is the standoff technique and another one is the contact technique.

Now, we come on to the contact technique. In case of the contact technique, the explosive charge in the form of a cartridge. So, here the explosive charge is in the form of a cartridge. In case of standoff technique the explosive charge may be of any kind - it can be some chemical, or it can be some gaseous mixture, or it can be some kind of a propellant.

So, the explosive charge in the form of cartridge is held in direct contact. So, important point to note here is the direct contact with the work piece, while the detonation is initiated. So, whenever we are creating or we are causing a detonation, the detonation is caused, when the explosive in the form of a cartridge is in the direct contact of the work piece that we are going to plastically deform.

In case of stand off technique, there was a distance between the work piece and the explosive charge that was called as the stand by distance. So, here there is no distance; the cartridge is in direct contact of the work piece material. So, the explosive charge in the form of the cartridge is held in direct contact with the work piece while the detonation is initiated. The detonation builds up extremely high pressures. So, there also a pressure pulse was created, here also extremely high pressure to the tune of 30,000 mega Pascal is created. So, when we detonate, the pressure rises, and on the surface of the work piece resulting in metal deformation and possible fracture.

So, as there is a direct contact, so there are number of parameters in this process that have to be controlled - What should be the type of the explosive? How much pressure it is going to generate? On which surface the metal is going to get deformed? Whether the cracking will take place or not. So, the limiting factor here or the limiting criterion here is the fracturing of the surface, because here we are deforming the metal to give it a desired shape. If the shape is not got and the metal fractures or the sheet fractures, then there is no point in caring out the explosive forming.

So, the detonation builds up extremely high pressures on the surface of the work piece, resulting in metal deformation and possible fractures. So, there are chances of a possible fracture in case of direct contact of the explosive with the sheet metal. The process is used often for bulging tubes. So, we will see, with the help of a figure, with the help of a diagram, that how we can bulge tubes using this contact technique.

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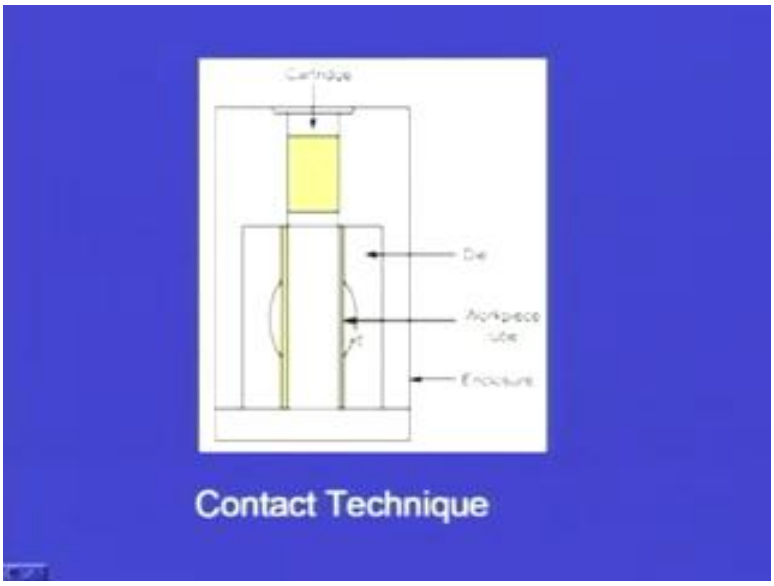

So, this gives a example. This is a diagram of a contact technique of explosive forming. So, here we see this yellow color, it is written - may not be too clear - it is cartridge; this is yellow portion; this is the cartridge; then this is the die. The die is having the cavity. This is the shape that we want to give to our raw material. So, raw material, in our case that is the work piece; this is our work piece - the solid portion

So, we see cartridge is in direct contact. As soon as the explosion will takes place, the work piece will be deformed plastically and we will get this shape. So, this is a tube. We see that inside it is hollow. This is a tube. So, this tube will bulge from here. So, die cavity has been made in such a way that we are going to create a bulge in the tube. So, bulging will takes place. In case of contact technique, the cartridge is in direct contact of the raw material or the work piece, and we can cause a bulging in the tube using this process of explosive forming.

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Then, what are the possible application areas of explosive forming? Explosive forming is mainly used in the aerospace industries, but has also found successful applications in the production of automotive related components. So, two important application fields, two important application areas are the aerospace industry as well as the automotive components.

So, explosive forming sometimes is also used for cladding of plates, sometimes when we want to join two plates, we can do this; one is a flyer plate, base plate; then we use a continuous explosive and we can clad the plates. So, in order depending on the final specifications or the final requirements of our final product or of our product we decide on the process that we are going choose. So explosive forming has been readily used in the aerospace industry as well as it has been used for making certain automotive components.

The process has the greatest potential in limited production prototype forming, and for forming large size components for which conventional tooling costs are prohibitively high. So, already these points have been addressed, but here, to summarize that size is no limitation in this case, but if we want to make a very large size of a product, the conventional tooling cost - already we have seen die manufacturing, in one of our previous lectures, how a die is manufactured. So, if we want to make a very big die, the tooling cost will be high. So, die in any case here also we require a die, but the similar type of matching punch arrangement is also required, but here no such punch arrangement is required; it is the explosive which is detonated; a pulse is generated; it impinges on the sheet metal and deforms it plastically. So, the important point to note here is that size is not limitation for the production prototype forming and for forming large size component.

So, suppose we want to make a prototype, it is not a regular production or a continuous production cycle. If it is only a prototype that we want to generate, then also this process holds advantage as compared to the normal operations. Similarly, if we want to make a very large size of a product, then also explosive forming has its advantage, advantageous position as compared to the other normal forming or conventional we should say, another conventional forming processes.

So, in order to summarize - what are the application areas? Explosive forming is mainly used in the aerospace industries, but has also found successful applications in the production of automotive components. The process has a greatest potential in limited production prototype forming. So, limited production means small number of parts and for forming large size components for which conventional tooling costs are prohibitively high. So, for conventional tooling wherever the tooling cost is too high, we can go for explosive forming.

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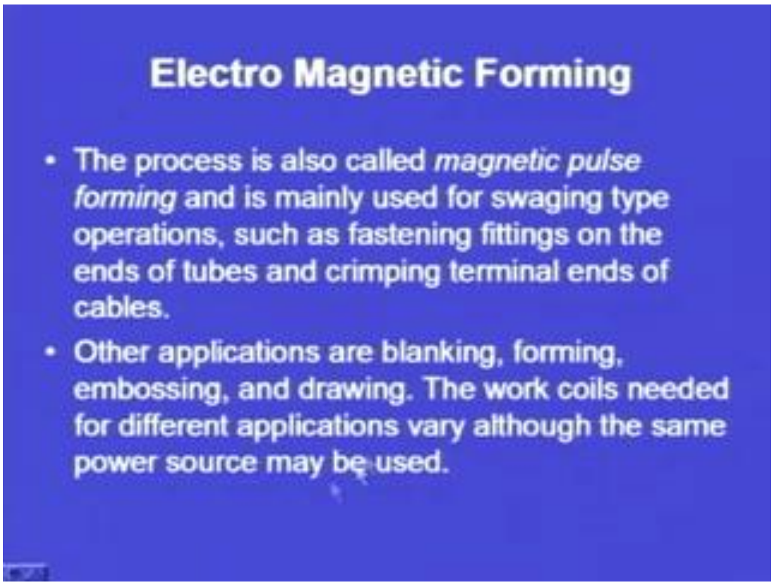

Now, we come on to the second particular category of high energy rate forming processes. The second process is electromagnetic forming. So, we will just have a overview what is this electromagnetic forming. The process is also called magnetic pulse forming and is mainly used for swaging type of operation. So, basic process of swaging, we have discussed in our previous lecture - what is swaging, what are the different types of shapes we can form using swaging operation. So, the process is also called magnetic pulse forming and is mainly used for swaging type of operations such as fastening fittings on the ends of the tube. Suppose there is a tube, and we want to fasten some fitting on the end of the tube, and crimping terminal ends of the cables. So, if some certain cables are there, and we want to crimp the end of those cables, then this particular process is particularly suitable or is most advantageous; it is most advantageous process in these kind of scenarios.

Other applications are blanking - we have already seen what is the operation of blanking, what is the blanking die punch type of arrangement, how it performs the operation, all that has already been seen. So, electromagnetic forming can also be used for blanking operation. Then it can be used for forming operation. It can be used for embossing and drawing.

So, in our lectures, we have already discussed the conventional techniques. In some of the lectures, we have seen that what is blanking, how it is done, what is forming, what is embossing; how we embossed different like coining etcetera; we have seen. Then drawing also, we have seen - what is deep drawing, what is tube drawing. So, all those operations can also be done using electromagnetic forming process.

Then the work coils needed for different applications vary, although the same power source may be used. So, the work coils that are required - the coils are required to pass the current. So, the coil - work coils - that are required may be different, but the power source that is used for converting the shape or providing the current or providing the power will remain the same. The power source will be same, but the coils may be required depending up on the final requirement of the product.

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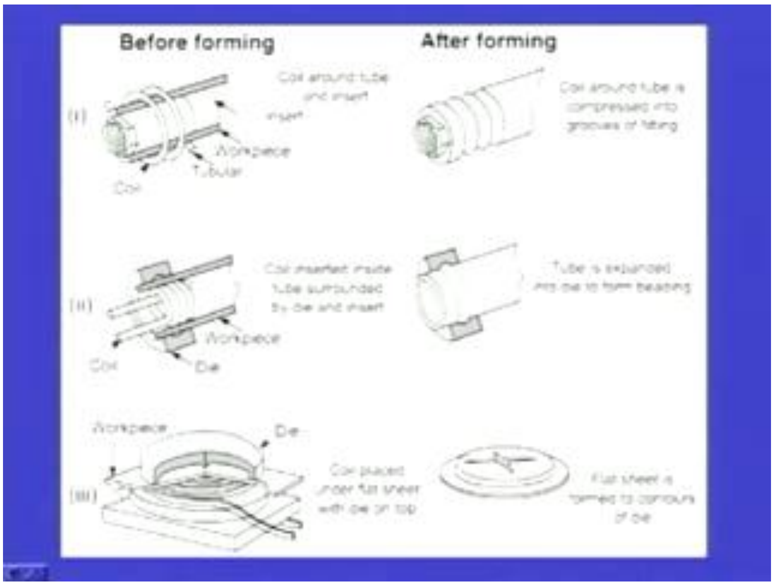

Now, this is an example. This, we can see, then later on we will see how these processes or what are the different functions that are being performed here, in this particular diagram. So, at the top we can see that is before forming; before forming this is the scenario; first, second, and third; three cases have been addressed here. Then after forming we are going to get this shape. So, how the diagram has been labeled. we can see. This is the coil that we were talking about. Then this is a tubular work piece - this coil is a tubular and this is the work piece - the solid portion - then this is the work piece, and then there is a insert in between, This is before forming.

And after forming, we are going to get this shape. So, this is coil around the tube and insert. So, there is a tube and an insert. There is a coil that is around the tube and insert, and here coil around tube is compressed into the grooves of fitting. This we can see. There are grooves have been formed. So, before forming there was no such groove, but after forming the grooves have been formed by the process of electromagnetic forming. How that happens, we will see now.

Then first, we will see the different... These are the some of the cases that have been taken. Then, there is a second case. Here the coil is inside the work piece. Here the coil was outside the work piece. This is the work piece - solid portion. The coil is outside, we can see. Here this is the work piece - the solid potion, which has been shown and inside is the coil. And this is the die in order to give the outer geometrical entity or outer geometrical feature to the product that we want to make.

So, the coil inserted inside the tube surrounded by die and insert. So, there is a die and insert. This is the die and the coil is inserted inside the tube. The coil is inserted inside the tube, surrounded by die and insert. So, what is the final product after forming? Tube is expanded into die to form a beading. So, a bead has been formed. This is the bead, and this is the die. Here also die has been shown. So, a bead has been formed.

Then the third case here this is the work piece - this plate, this solid plate - not visible; this top portion is the die - this is the die; and this is the work piece. And the coil is placed under flat sheet with die on top. So, here we can see, this is the coil that has been placed - the circular coil has been placed here. On top of it there is a work piece and on top of that there is a die. So, the coil has been placed under the flat sheet. This is the flat sheet, this is the flat sheet; that is the work piece with die on the top; the die is there on the top. Now, the flat sheet is formed to contours of die. So, whatever are the contours of the die, the flat sheet will be formed according to those contours. So, whatever are the contours inside the die, the flat sheet will take the shape of the die.

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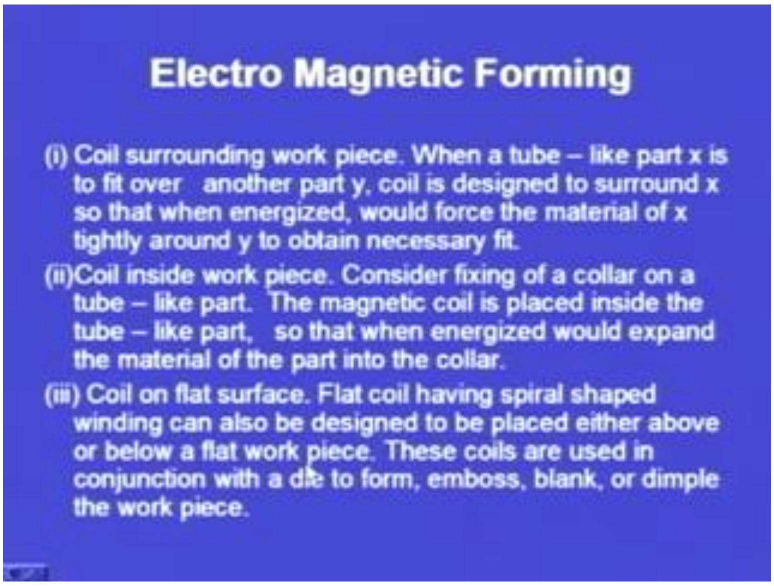

Now, there are three cases. The first case is coil surrounding work piece. So, there is a coil that was surrounding the work piece. So, when a tube like part x is fit over another part y; so x and y are the two parts - the coil and the tube or the tube and the coil. Coil is designed to surround x, so that when energized - energized means that when we are going to provide the energy, which will be electrical energy or the voltage in this particular case - would force the material or x tightly around y to obtain necessary fit.

So, in first case, that coil was outside the tube or outside the work piece and we are going to create a fit using, by passing, the electrical energy, then the coil inside the work piece. First case was the coil was outside the work piece; in second case, the coil is inside the work piece. So, the coil inside the work piece. Consider fixing of a collar on a tube like part. So, if we want to fix up a collar on a tube like part, the magnetic coil is placed inside the tube like part.

So, we have seen in the diagram the magnetic coil is placed inside the tube like part. So, that when energized, again here we are providing certain energy which would expand the material of the part into the collar. So, whatever part we want to provide inside the collar it will expand that material. So, when energized, it will expand the material and it will form a part of the collar. Now, the third case is the coil on flat surface. There is a flat surface and there is a coil. Flat coil having spiral shaped winding can also be designed to be placed either above or below the flat work piece.

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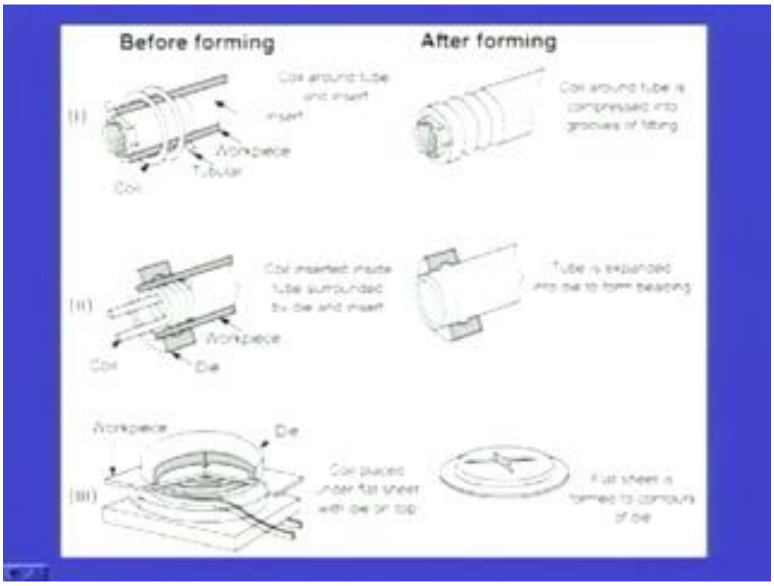

In our case, we can see again, in our case this is the work piece and the coil is placed under flat surface with die on top. So, the coil is below the work piece. So, we can see the coil on the flat surface; flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece.

So, flat work piece, a coil can be either top of this or it can be below that. These coils are used in conjunction with die to form emboss blank or dimple the work piece. So, there is a flat sheet which we are using, if we want to emboss it, if we want to blank it, or if we want to create a dimple on the work piece, the coil can be placed either on top of it or it can be placed below that.

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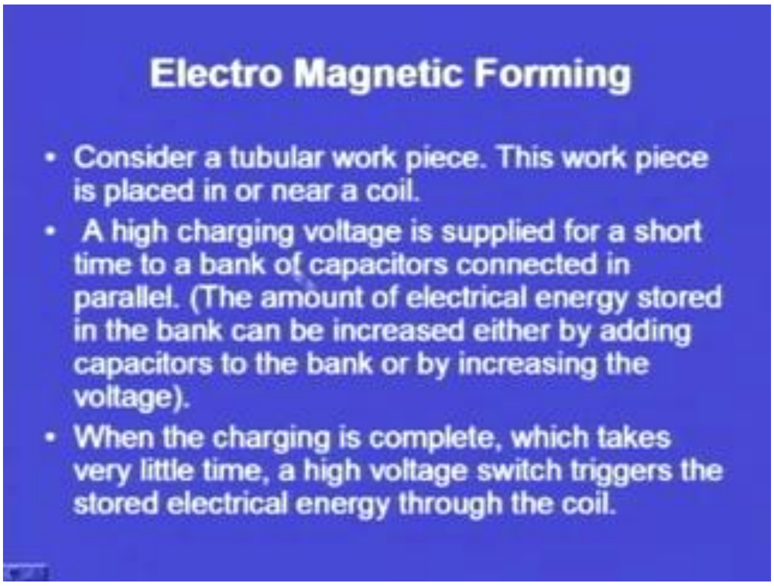

So, electromagnetic forming. Now we can take one particular example and try to understand how it happens. Now, consider a tubular work piece. So, there is a tubular work piece in the form of a tube. This work piece is placed in or near a coil. So, this work piece - this tubular work piece - is placed near to the coil. A high charging voltage. So, charging voltage is high in case of electromagnetic forming. A high charging voltage is supplied for a short time. So, when we started our discussion on high energy rate forming processes, we have seen that high energy is provided for a very brief interval of time. The same principle is used here. A high charging voltage is supplied for a short time to bank of capacitors connected in parallel. So, there are capacitors that have been connected in parallel. The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage. So, this is a normal procedure. We can add on the capacitors or we can increase the voltage. So, electrical energy can be controlled; it can be increased also. So, when charging is complete, we are going to charge this bank of capacitors. I can point again. We can see a high charging voltage is supplied for a short time to a bank of capacitors connected in parallel.

So, when the charging is complete which takes very little time. So, charging will not take too much of time. A high voltage switch triggers the stored electrical energy through the coil. So, we are using a coil, and when the charging is complete, a high voltage switch triggers the stored electrical energy through the coil.

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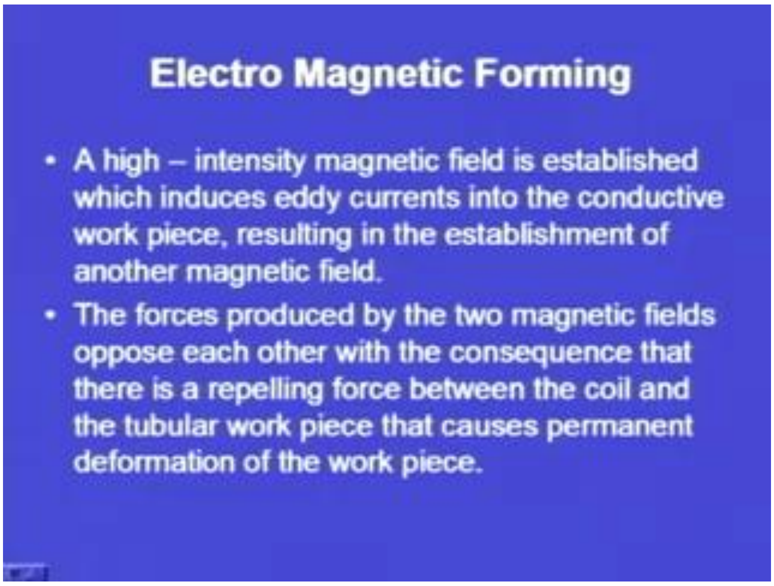

A high intensity magnetic field is established which induces Eddy currents into the conductive work piece. So, the work piece here is a conductive work piece. A high intensity magnetic field is established, which induces Eddy current into the conductive work piece, resulting in the establishment of another magnetic field. So, magnetic field will be produced, because of the Eddy currents that are being generated. The force is produced by the two magnetic fields. So, now, these two magnetic fields will interact. The force is produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece, that causes permanent deformation of the work piece.

So, repelling force will be created, because of the interaction of the two magnetic fields that have been established, because of the voltage that has been provided - a high voltage that has been provided. So, repelling force between the coil and the tubular work piece that causes the permanent deformation of the work piece. So, the deformation will take place because of the electromagnetic action.

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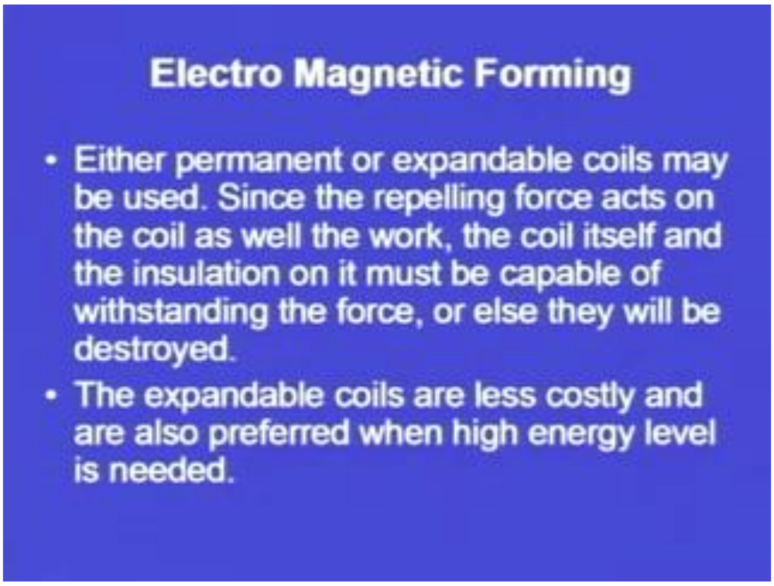

Either permanent or expandable coils may be used. So, we can used either permanent or expandable coil. Since the repelling force acts on the coil as well as the work, the coil itself, and the insulation on it, must be capable of withstanding the force. Now, the force is acting - repelling force - on both; it is not in case of explosive forming, after detonation the explosive material will explode; so, again we have to supply the explosive. But here, the coil we can use either permanent or it can be expandable coil, because the forces are also acting, the repelling forces are being generated and the forces are also acting on the coil.

So, either permanent or expandable coils may be used, since the repelling force acts on the coil as well as the work. The coil itself and the insulation on it must be capable of withstanding the force. So, it is it should not so happen that the coil gets damaged or the coil gets fail or else they will be destroyed. So, if it does not have the subsequent strength or it does not have the required strength, there are chances that the coil may fail. The expandable coils are less costly and are also preferred when high energy levels are needed. So, when we need a very high energy level, in those particular cases, we may go for expandable coils, which may get destroyed during the operation.

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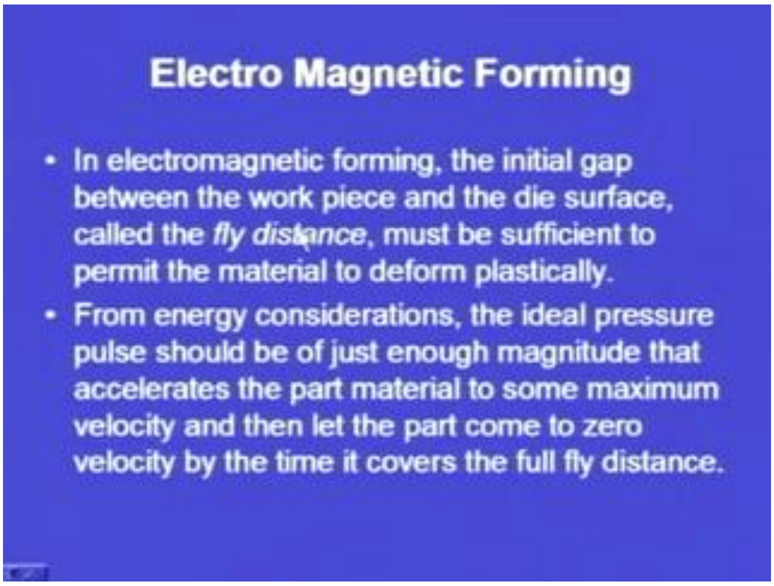

In electromagnetic forming, the initial gap between the work piece and the die surface - there is a gap between the work piece and die surface, called the fly distance - must be sufficient to permit the material to deform plastically. So, this fly distance that we have discussed, should be sufficient; it should not be too less.

Then, from energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity, and then, let the part come to zero velocity by the time it covers the full fly distance. So, what is fly distance? We have seen in electromagnetic forming the initial gap between the work piece. So, suppose this is the work piece and this is the die surface. So, there is a distance between the work piece and the die surface - this is called the fly distance. This must be sufficient to permit the material to deform plastically. If we are joining it, then there are no, there is no chance that the material is going to plastically deform. So, there is a some fly distance has to be provided.

And from energy consideration the ideal pressure pulse should be just enough magnitude that it accelerates the part material to some maximum velocity. And then, let the part come to zero velocity by the time it covers the full fly distance; it is very, very clear. All forming coils fail. Expandable coils fails sooner than durable coils and because extremely high voltages and currents are involved, it is essential that proper safety precautions are observed by the production and maintenance personnel.

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So, certain health hazards are possible, if we are going to use this high energy rate forming processes. And more over if we are to talk about electromagnetic forming process, high voltage, high current is involved and these coils because of the force they may sometimes fail also. So, these expandable coils, if they are not so durable, they will fail after certain cycles of operation. So, we have to take adequate care that no particular health problem or no particular accident - we should say here, there are no health problems, but the accident problems or accident prone process. So, accident should be avoided and every care should be taken in order to avoid any kind of failure of the system.

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Then coming on to the applications of this process that is electromagnetic forming. Electromagnetic forming process is capable of a wide variety of forming and assembly operations. It has found extensive applications in the fabrication of hollow, non-circular or asymmetrical shapes from tubular stock. So, tubular stock can be converted into different types of shapes. The compression applications involve swaging to produce compression, tensile and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together. So, there are number of application areas of this high energy rate forming process.

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Then another application areas are flat coils have been used on flat sheets to produce stretch - that is internal case, and shrink that is the external flanges on ring and disc shaped work pieces. Electromagnetic forming has also been used to perform shearing piercing and riveting. So, till now, we have seen that high energy rate forming processes are important. What is the application spectrum of these processes? That the shape is no limitation; the size is also no limitation, although there may be certain limitations on certain intricate parts, but more often than not, certain shapes that are difficult to form using the normal procedures or normal forming operations can be formed using high energy rate forming processes. Then another application spectrum is the size, where the size is no limitation here; whereas, the tooling costs will be considerably higher, if we choose any other high energy or any other conventional process.

So, if we have, if we take into account the particular shape and the punch and the die arrangement, tooling cost is considerably higher, but here in case of high energy rate forming processes, the tooling cost is not that much; the tooling cost is considerably less and we are able to produce the parts - the desired parts - to a desired shape and to a desired size.

Similarly, if we want to go for a low quantity production, if we want to only make a prototype, then also high energy rate forming processes are considerably advantageous as compared to the conventional forming processes. So, today we have discussed all these things. There is a last process, that is electro hydraulic forming, that has been left; that we will cover in our subsequent lecture.

Thank you.