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ANALYSIS OF SPLINE PROFILE AND ITS MANUFACTURING

[1]Mr. TUMPALA UMA SANTHOSH, [2]R Art Babu, [3]A Vinutha, [4]P.N. SHARMA

Abstract: The project entitled "THE ANALYSIS OF SPLINE PROFILE AND ITS MANUFACTURING". Which explores information about spline cutter profile, spline cutting and splines manufacturing.

A series of projections and slots used instead of a key to prevent relative rotation of cylindrically fitted machine parts. Splines are several projections machined on a shaft, the shafts fits into mating bore is called a spline fitting. Spline are made in two forms square and involutes.

Spline profiles are mostly important in spline cutting process so the analysis of spline profile is most important in the process of splines manufacturing.The designation of a spline profile is module, pitch circle diameter, number of teeth.

Mostly in industries spline profiles are involutes splines, in which pressure angle and module are very important considerations for spline cutting. Mostly in spline profile 30 degrees pressure angle is widely used in industries.

If we change any parameter in involutes spline curve there should be some effect on involutes spline causes to change the pitch center line and tooth thickness. This results making of two spline profiles are difficult and causes to failure of splines.

Spline cutting is the process carried out internally and externally. In internal splines broaching and slotting operations are carried out and at the same time external splines can be manufactured by the process of hobbing, milling and shaping. In spline cutting carefully analyse the teeths provided on the end of shafts and stresses acted on the teeth.

After analysing the teeth profile in spline cutting, analyse the process of spline manufacturing. In spline hobbing, the hob has a number of cutting tools provided and generates the spline profile on a shaft and also on shaping and milling single cutting tool produces profile cutting operation on a shaft.

VISAKHAPATNAM STEEL PLANT- AND ITS INTRODUCTION

With a view to give impetus to industrial growth and to meet the inspirations of south India, government of India has established integrated steel plants in the public sector at Visakhapatnam in 1970 for a modern sophisticated steel plant having an annual capacity of 3.0 million tons of hot metal. Unlike other steel plants VSP is the biggest project and the most modern steel plant, located in between the NH-5 and the bay of Bengal lays a stretch of the land strewn with hillocks, valleys a natural creek and green forest south west of Visakhapatnam harbor. And this is the first shore based plant at Visakhapatnam.

VSP is locate at a distance of 16 km west of city of destiny lies in between the northern the northern boundary of the NH no. 5(Chennai to Kolkata) and 7 km to south west of the Howrah-Chennai railway line. It occupies 25,780 acres of land comprising 6,400 for the production facilities, 6620 acres for the township & 12,760 for the o0ther facilities.

VSP has become the first integrated steel plant in the country to be certified to all international standards for quality (ISO 9001), for Environmental management (ISO 14001) and for the occupational health & safety (OHSAS 18001) the certificate covers quality systems of all operational, maintenance, service units besides purchase systems. VSP exports quality pig iron & steel products to Sri Lanka, Myanmar, Nepal, Middle East, USA & South East Asia. The plant was registered under corporate name RashtriyaIspat Nigam Limited on 18th February 1982. Presently plant has a capacity to produce 3Mt liquid steel and 2.656MT of saleable steel.

DEPARTMENTS IN VISAKHAPATNAM STEEL PLANT:

The various departments available in the VSP include:
RMHP (RAW MATERIAL HANDLING PLANT)
CO & CCP (COKE OVENS & COAL CHEMICAL PLANT)

SP (SINTER PLANT)
BF (BLAST FURNACE)
SMS (STEEL MELTING PLANT)
ROLLING MILLS
RS & RS (ROLL SHOP & REPAIR SHOP)
TPP (TERMAL POWER PLANT)

RMHP (RAW MATERIAL HANDLING PLANT):

VSP annually requires quality materials like iron ore, fluxes, coking & non –coking coals etc… for the production of 3 MT of steel using 12-13 MT of raw materials. In order to handle the large volume of the incoming raw material received from the different sources and to ensure timely supply of the consistent quality of feed materials to various other departments for carrying out the vital functions.

CO & CPP (COKE OVENS & COAL CHEMICAL PLANT):

Coke is manufactured by the heating of the crushed coking coal in the absence of air at 1273 k for a span of 16 to 18 hours. The coal chemicals such as Benzol, Ammonium sulphate etc… are extracted in the coal chemical plant for the CO gas.

SP (SINTER PLANT):

Sinter is a hard & porous ferrous material obtained by agglomeration of iron ore fines, coke breeze, Lime stone fines, Metallurgical wastes, etc…sinter is a better feed material to the blast furnace in comparison to the iron ore lumps and its usage in BF help in increasing productivity, decreasing the coke rate & improving the quality of the hot metal produced.

BF (BLAST FURNACE):

Hot metal is produced in the Blast furnaces which are tall vertical furnaces and it runs with blast at high pressures & temperatures. Raw materials are charged from top and the hot blast at 1373 k to 1573 k and 5.75 Kg/cm2 is blown from bottom. VSP has two 3200 cu meter BF's with conveyor charging and named as "GODAVARI" & "KRISHNA".

SMS (STEEL MELTING SHOP):

Steel generated has lot number of impurities in it which makes it unfit for engineering practices. So in order to remove the impurities from the steel oxygen is blown to enter in to the convertor so that the impurities gets oxidized and form slag with basic fluxes as that of lime. By controlling the oxygen blow the different grades of superior quality can be obtained.

ROLLING MILLS:

Blooms produced from the continuous casting machines do not find much applications as such and are required to be shaped in to products such as billets, round, squares, by rolling them in the sophisticated, high capacity, high speed , fully automated rolling mills, namely Light & Medium Merchant Mill, RS & RS (ROLL SHOP & REPAIR SHOP):

These caters to the needs of three mills in respect of the roll assemblies, guides, few maintenance spares and roll design. The main activity of this shop is roll pass design, grooving of the rolls,assembly of rolls with bearings, preparation of their guides and their service and manufacture/repair of mill maintenance spares. This constitute Roll Shop-1,Roll Shop-2 and finally Area repair shop.

ENGINEERING SHOPS & FOUNDRY (ES & F)

Engineering Shops & Foundry department is set up to meet the requirements of spares, repair of assemblies and reclamation of various jobs of different departments. This complex consists of
1. Central Machine Shop (CMS)
2. Steel Structural Shop (SSS)
3. Foundry
4. Forge Shop (FS)
5. Utility Equipment Repair Shop (UERS).

CENTRAL MACHINE SHOP (CMS):

INPUTS: Iron and steel castings, forgings , rolled sections, repair and rectification parts, non ferrous castings.

PRODUCTS AND SERVICES:

In Central machine shop, various spares like Gears, Shafts, Crusher liners, hammers, machined castings and fabricated jobs are made. In addition to the manufacturing spares, assembly and repair jobs like gear boxes, Crusher, bearing housings, stands of SMS are taken up. Over 100 major machines including lathes, milling, Plano milling, boring, slotting, shaping, grinding etc. are available to take up machining of spares. 2 presses of 630 ton, 315 ton and dynamic balancing machine of 25 ton capacity, are provided at CMS for repair of assemblies.

STEEL STRUCTURAL SHOP (SSS):

At Structural shop of ES&F, structural jobs of various departments like coke bucket, ladle, SRC body, Wagons, Shells, ducts etc. are being fabricated or repaired as per the requirement of departments. The equipments available are Bending machine-25mm capacity, Shearing machine-25mm capacity, CNC profile gas cutting machine, welding machines, gas cutting sets, other tools and tackles.

FOUNDRY:

In Foundry, castings of Iron, steel and non-ferrous are produced based on the projection of Customer departments. 8 ton Arc furnace, 2nos of 5ton Induction furnaces and 1 ton crucible furnace for non-ferrous jobs and sand plant for preparation of sand for moulds are available for making castings. Major jobs like Hot metal runners of 10 tons weight Bottom funnel(5 ton), Emergency containers(7 ton), lower mantle and Bowl liners(3 tons each) etc are produced.

FORGE SHOP (FS):

In Forge shop, preparation of raw materials for shafts, coupling flanges, gears etc and also of forge shapes such as crusher hammer heads, V -hooks, drill rods with the help of 0.5 ton, 2 ton, 3 ton pneumatic hammers, manipulators, heating furnaces is carried out.

The shop is designed for production of forgings for shafts, coupling flanges, etc., and also of forged shapes such as crusher hammer heads, special bolts, nuts, etc. The annual production from the shop is 2400 tons. In heavy forging section, open dye forgings of long shafts, gear blanks, couplings, etc. is made with the help of 2 ton & 3 ton bridge type pneumatic hammers. Each hammer will be provided with twin chamber heating furnaces. Floor type manipulator and GIB cranes are provided for handling heavy jobs. In general forging section 1T, 500 KG, and, 200Kg hammers are provided. A 2 Ton drop stamp hammer with a heating furnace, trimming press, etc. is provided for stamping. For cutting them to size, a cold saw, a billet shear and gas cutting facilities are provided. For stress relieving, a bogie type annealing furnace is provided.

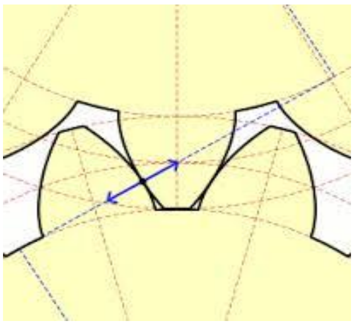
UTILITY EQUIPMENT REPAIR SHOP (UERS):

In Utility Equipment Repair Shop, repair of ventilation equipments, valves, fans and impellers is carried out. Equipments like shearing machine, bending machine, presses, lathes etc are provided to take up different repair and manufacturing activities.

INTRODUCTION TO GEARS AND ITS ANALYSIS

Gears are of round and cylindrical mechanical component with teeth, used to transmit power. Gears are designed to mesh with one another and can alter the speed, torque, or direstion of mechanical energy.

LAW OF GEARING



- The common normal at the action between two teeth must always pass through a pitch point in such a way that it divides line joining the centers of the mating gears in the reverse ratio of angular velocity.
- Increasing pressure angle increases the width of the base of the gear tooth, leading to greater strength and load carrying capacity.
- Decreasing pressure angle providing lower backlash, smoother operation and less sensitivity to manufacturing errors.
- *w1/w2=o2p/o1p
- pitch point divides the line between the line of centers and its position decides the velocity ratio of two teeth.
- Velocity ratio is equal to inverse ratio of the diameters of their pitch circle.
- Fundamental law of gear tooth action may be started of follows (for gears with fixed center distance)(to get a constant velocity ratio).
- The two profiles which satisfying the requirement are called conjugate profile. The common normal at the point of action between two teeth must always pass through pitch point. in such way that it divides line joining the centers of the two mating gears in the reverse ratio of angular velocities.

GEAR NOMENCLATURE

ADDENDUM:

The addendum is the height by which a tooth of a gear projects beyond (outside for external, or inside for internal) the standard pitch circle or pitch line; also, the radial distance between the pitch diameter and the outside diameter.

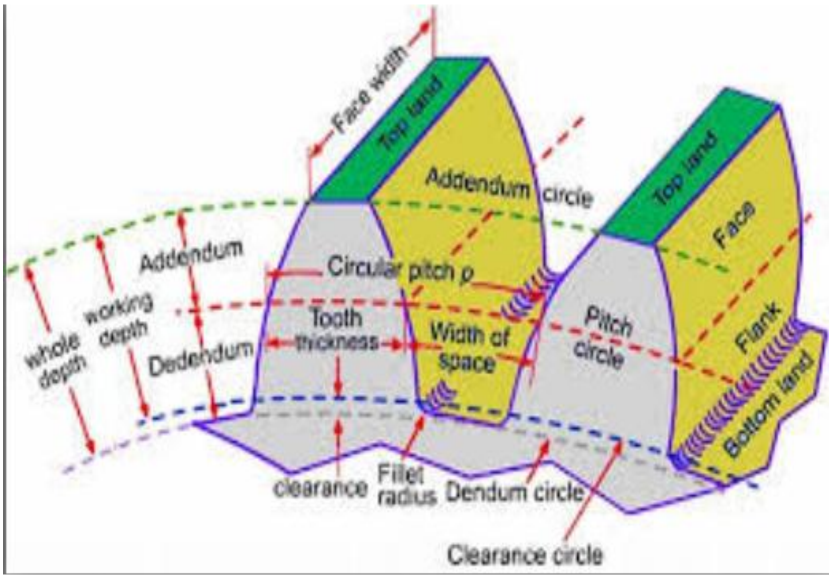


Fig. INVOLUTE GEAR TOOTH PROFILE

ADDENDUM ANGLE:

Addendum angle in a bevel gear, is the angle between elements of the face cone and pitch cone.

DEDENDUM:

The Dedendum is the radial length of a tooth from the pitch circle to root of the teeth.

PITCH CIRCLE:

Theoretical circle upon which all gears calculations are usually based pitch circles of mating gears are tangent to one another

CIRCULAR PITCH:

A distance measured on the pitch circle form a point on tooth to a corresponding point on an adjacent tooth ; it is equal to the sum of the tooth thickness and the width of space.

P= circular pitch

CLEARANCE CIRCLE:

A circle that is tangent to the addendum circle of the mating gear is called clearance circle.

CLEARANCE:

The amount by which the deddendum in a given gear exceeds the addendum of a mating gear.

DIAMETRAL PITCH:

Is the ratio of the number of teeth on the gear to the pitch diameter, the module is the reciprocal of the diametral pitch.

P = N/d (N = No of gear teeth)
(d = pitch diameter)
m = d/N = 1/P (module is usually in millimeter)

BOTTOM LAND:

The bottom land is the surface at the bottom of a gear tooth space adjoining the fillet.

TOP LAND:

Top land is the (sometimes flat) surface of the top of a gear tooth.

BACK LASH:

The amount by which the width of a tooth space exceeds the thickness of the engaging tooth, measured on the pitch circle.

BACK ANGLE:

The back angle of a bevel gear is the angle between an element of the back cone and a plane of rotation, and usually is equal to the pitch angle.

MODULE:

Module is the value of the module in a normal plane of a helical gear or worm.

OFF SET:

Off set is the perpendicular distance between the axes of hypoid gears of offset face gears.

BASE CIRCLE:

The base cylinder corresponds to base circle, and is the cylinder from which involute tooth surfaces are developed.

BASE DIAMETER:

The base diameter of an involute gear is the diameter of the base circle.

FACE (TIP) ANGLE:

Face (tip) angle in a bevel or hypoid gear, is the angle between an element of the face cone and its axis.

FACE CONE:

The face cone also known as the tip cone is the imaginary surface that coincides with the tops of the teeth of a bevel or hypoid gear.

FRONT ANGLE:

The front angle in a bevel gear, denotes the angle between an element of the front cone and a plane of rotation, and usually equals the pitch angle.

HELIX RACK:

A helical rack has a planar pitch surface and teeth that are oblique to the direction of motion.

PITCH ANGLE:

Pitch angle in bevel gears is the angle between an element of a pitch cone and its axis. In external and internal bevel gears, the pitch angles are respectively less than and greater than 90 degrees.

GEARS CLASSIFICATION

SPUR GEAR:

Spur gears are the most commonly used gear type. They are characterized by teeth which areperpendicular to the face of the gear. Spur gears are by far the most commonly available, and are generally the least expensive. The basic descriptive geometry for a spur gear is shown in the figure below.

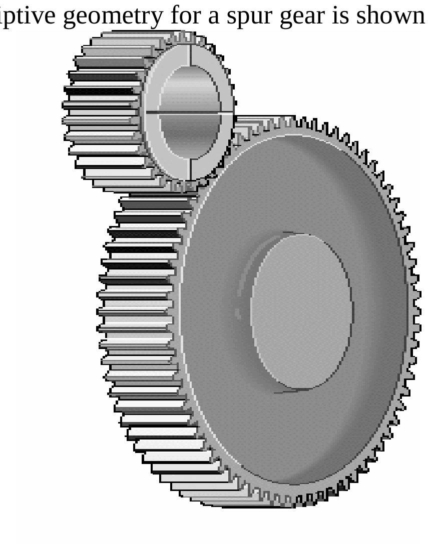


Fig. SPUR GEAR

HELICAL GEAR:

Helical gears are similar to the spur gear except that the teeth are at an angle to the shaft, rather than parallel to it as in a spur gear. (See the references for more specific information). The resulting teeth are longer than the teeth on a spur gear of equivalent pitch diameter. The longer teeth cause helical gears to have the following differences from spur gears of the same size:

- Tooth strength is greater because the teeth are longer,
- Greater surface contact on the teeth allows a helical gear to carry more load than a spur gear
- The longer surface of contact reduces the efficiency of a helical gear relative to a spur gear.
- Helical gears may be used to mesh two shafts that are not parallel, although they are still primarily use in parallel shaft applications. A special application in which helical gears are used is a crossed gear mesh, in which the two shafts are perpendicular to each other:
- The basic descriptive geometry for a helical gear is essentially the same as that of the spur gear, except that the helix angle must be added as a parameter.

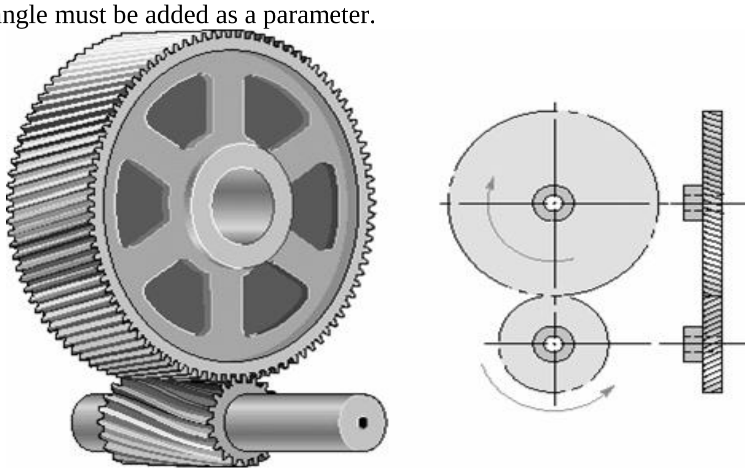
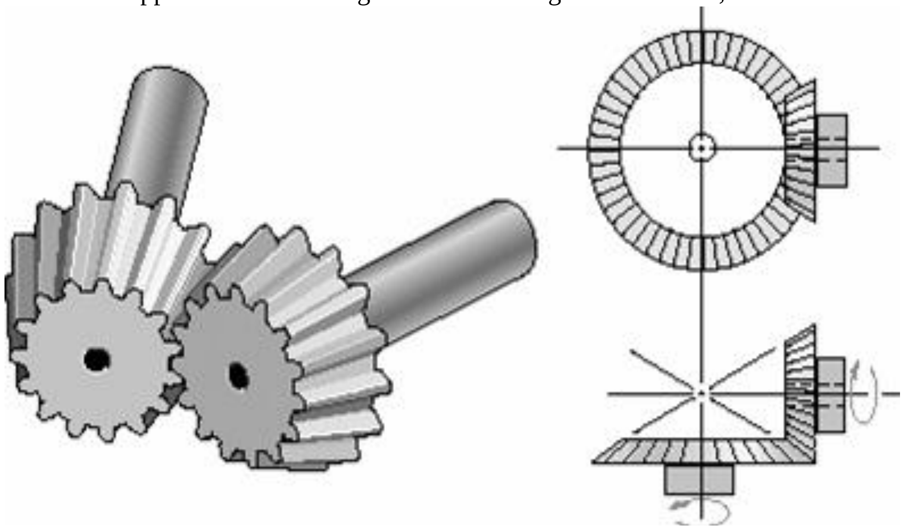


Fig. HELICAL GEAR

BEVEL GEAR:

Bevel gears are primarily used to transfer torque between intersecting shafts. The teeth of these gears are formed on a conical surface. Standard bevel gears have teeth which are cut straight and are all parallel to the line pointing the apex of the cone on which the teeth are based. Spiral bevel gears are also available which have teeth that form arcs. Hypocycloid bevel gears are a special type of spiral gear that will allow nonintersecting, non-parallel shafts to mesh. Straight tool bevel gears are generally considered the best choice for systems with speeds lower than 1000 feet per minute: they commonly become noisy above this point.

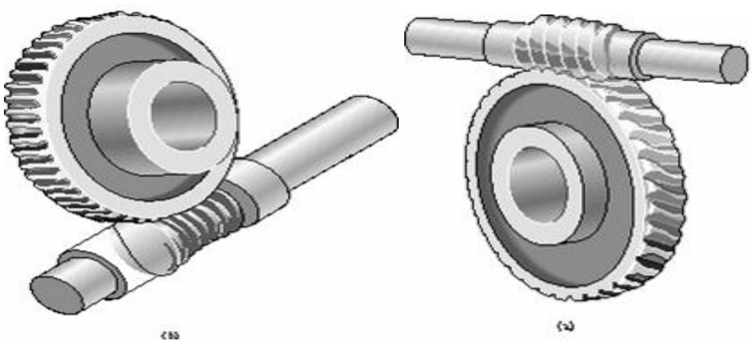
One of the most common applications of bevel gears is the bevel gear differential,



WORM GEAR:

Worm gears are special gears that resemble screws, and can be used to drive spur gears or helical gears.

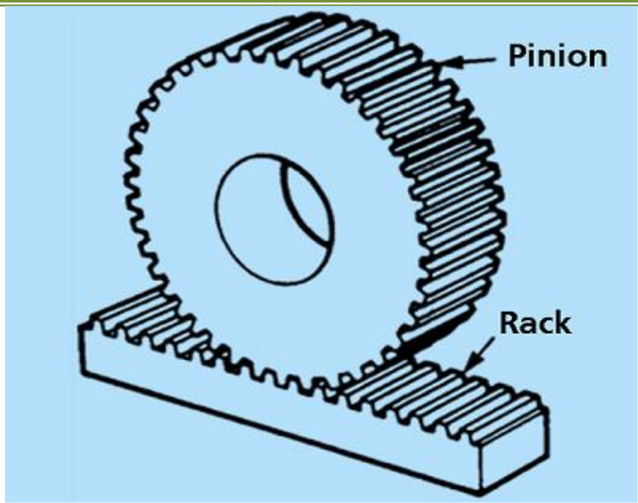
- Worm gears, like helical gears, allow two non-intersecting 'skew' shafts to mesh. Normally, the two shafts are all right angles to each other. A worm gear is equivalent to a V-type screw thread. Another way of looking at a worm gear is that it is a helical gear with a very high helix angle.
- Worm gears are normally used when a high gear ratio is desired, or again when the shafts are perpendicular to each other. One very important feature of worm gear meshes that is often of use is their *irreversibility*.
-



RACK & PINION (STRAIGHT) GEARS:

Racks are straight gears that are used to convert rotational motion to translational motion by means of a gear mesh. (They are in theory a gear with an infinite pitch diameter). In theory, the torque and angular velocity of the pinion gear are related to the Force and the velocity of the rack by the radius of the pinion gear,

- Perhaps the most well-known application of a rack is the rack and pinion steering system used on many cars in the past.



ANALYSIS OF GEAR TRANSMISSION

A machine consists of a power source and a power transmission system, which provides controlled application of the power. Merriam-Webster defines *transmission* as an assembly of parts including the speed-changing gears and the propeller shaft by which the power is transmitted from an engine to a live axle. Often transmission refers simply to the gearbox that uses gears and gear trains to provide speed and torque conversions from a rotating power source to another device.

In British English, the term *transmission* refers to the whole drive train, including clutch, gearbox, prop shaft (for rear-wheel drive), differential, and final drive shafts. In American English, however, the term refers more specifically to the gearbox alone, and the usage details are different.

The most common use is in motor vehicle, where the transmission adapts the output of the internal combustion engine to the drive wheels. Such engines need to operate at a relatively high rotational speed, which is inappropriate for starting, stopping, and slower travel. The transmission reduces the higher engine speed to the slower wheel speed, increasing torque in the process. Transmissions are also used on pedal bicycles, fixed machines, and anywhere rotational speed and torque must be adapted.

Often, a transmission has multiple gear ratios (or simply "gears"), with the ability to switch between them as speed varies. This switching may be done manually (by the operator), or automatically. Directional (forward and reverse) control may also be provided. Single-ratio transmissions also exist, which simply change the speed and torque (and sometimes direction) of motor output.

In motor vehicles, the transmission generally is connected to the engine crankshaft via a flywheel and/or clutch and/or fluid coupling, partly because internal combustion engines cannot run below a particular speed. The output of the transmission is transmitted via driveshaft to one or more differential, which in turn, drive the wheels. While a differential may also provide gear reduction, its primary purpose is to permit the wheels at either end of an axle to rotate at different speeds (essential to avoid wheel slippage on turns) as it changes the direction of rotation.

Conventional gear/belt transmissions are not the only mechanism for speed/torque adaptation. Alternative mechanisms include torque converter and power transformation.

GEAR MANUFACTURING PROCESS

MATERIALS USED:

The majority of gears are composed of carbon and low-alloy steels, including carburised steels. Among the carburised steels used in gears are 1018, 1524, 4026, 4118, 4320, 4620, 4820, 8620 and 9310. The intended gear use will dictate the material used in its creation. For example gears to be used in food processing are made of stainless steels or nickel-base alloys because of their corrosion resistance.

PROCESSES:

There are multiple ways in which gear blanks can be shaped through the cutting and finishing processes.

GEAR CUTTING PROCESS:

- Hobbing
- Shaping
- Planing
- Milling

GEAR FINISHNG PROCESS:

- Grinding
- Short blasting
- Shaving
- Phosphate coating

GEAR FORMING (NON- CUTTING) PROCESS:

- Extrusion
- Powder metallurgy
- Stamping
- Casting
- Roll-Forming (Spline Rolling)

HOBBING PROCESS

Hobbing uses a hobbing machine with two skew spindles, one mounted with a blank workpiece and the other with the hob. The angle between the hob's spindle and the workpiece's spindle varies, depending on the type of product being produced. For example, if a spur gear is being produced, then the hob is angled equal to the helix angle of the hob; if a helical gear is being produced then the angle must be increased by the same amount as the helix angle of the helical gear.The two shafts are rotated at a proportional ratio, which determines the number of teeth on the blank; for example, if the gear ratio is 40:1 the hob rotates 40 times to each turn of the blank, which produces 40 teeth in the blank. Note that the previous example only holds true for a single threaded hob; if the hob has multiple threads then the speed ratio must be multiplied by the number of threads on the hob. The hob is then fed up into workpiece until the correct tooth depth is obtained. Finally the hob is fed through the workpiece parallel to the blank's axis of rotation.

Up to five teeth can be cut into the workpiece at the same time. Often multiple gears are cut at the same time.

For very large gears the blank can be gashed to the rough shape first to make hobbing easier.

EQUIPMENT:

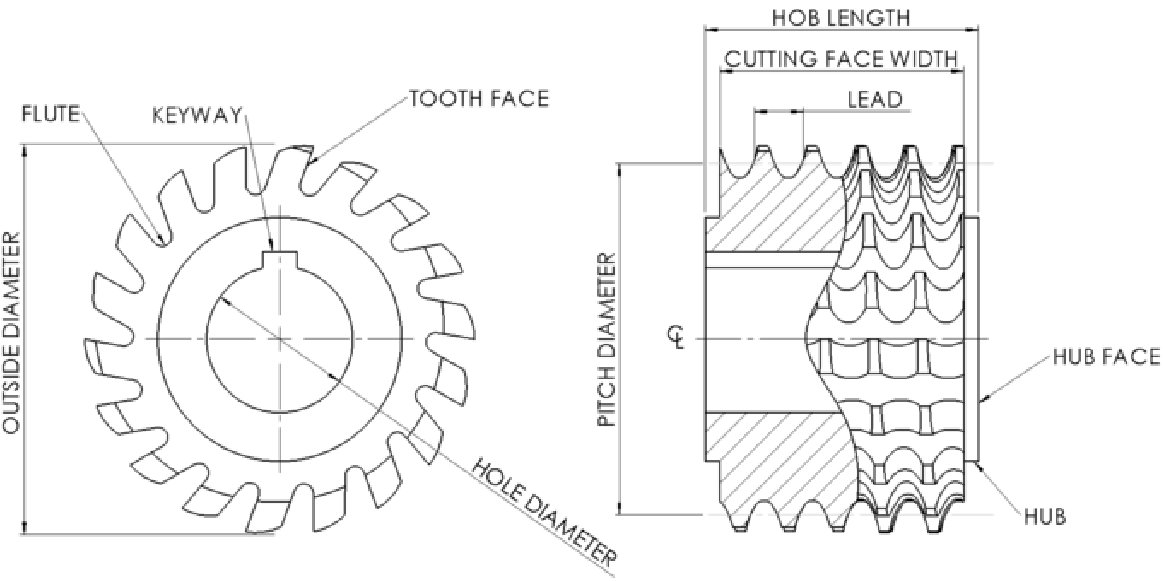
A horizontal hobbing machining

Modern hobbing machines, also known as hobbers, are fully automated machines that come in many sizes, because they need to be able to produce anything from tiny instrument gears up to 10 ft (3.0 m) diameter marine gears. Each gear hobbing machine typically consists of a chuck and tailstock, to hold the workpiece or a spindle, a spindle on which the hob is mounted, and a drive motor.

For a tooth profile which is a theoretical involute, the fundamental rack is straight-sided, with sides inclined at the pressure angle of the tooth form, with flat top and bottom. The necessary addendum correction to allow the use of small-numbered pinions can either be obtained by suitable modification of this rack to a cycloidal form at the tips, or by hobbing at other than the theoretical pitch circle diameter. Since the gear ratio between hob and blank is fixed, the resulting gear will have the correct pitch on the pitch circle, but the tooth thickness will not be equal to the space width.

Hobbing machines are characterised by the largest module or pitch diameter it can generate. For example, a 10 in (250 mm) capacity machine can generate gears with a 10 in pitch diameter and usually a maximum of a 10 in face width. Most hobbing machines are vertical hobbers, which means the blank is mounted vertically. Horizontal hobbing machines are usually used for cutting longer workpieces; i.e. cutting splines on the end of a shaft.

A gear hob in a hobbing machine with a finished gear.



Hobbing is used to produce most throated worm wheels, but certain tooth profiles cannot be hobbed. If any portion of the hob profile is perpendicular to the axis then it will have no cutting clearance generated by the usual backing off process, and it will not cut well.

SHAPING PROCESS:

In this process, a pinion shaped cutter is used which carries clearance on the tooth face ond sides. It carries a hole in the centre for mounting on a stubarbor or spindle of the machine. The cutter is mounted with its axis vertically and is reciprocated up and down by sliding the spindle head along the vertical ways on the machine. In addition to reciprocating motion, the cutter and gear blank, both are rotated slowly about their own axis.

MILLING PROCESS:

For cutting a gear on a milling machine, the gear blank is mounted on an arbor which is supported between a dead centre and a lieu centre in the dering head. The cutter is mounted on the arbor of the cutter, must be aligned exactly vertically with the centre line of indexing head spindle. The table of the machine is moved upward until the cutter just touches the periphery of the gear blank. The vertical feed dial is set to zero. The table is then moved horizontally until the cutter clears the gear blank.

PLANNING PROCESS:

Inside the mold or die during the casting process.Planing is a manufacturing process of material removal in which the workpiece reciprocates against a stationary single-point cutting tool producing a plane or sculpted surface. Planing is analogous to shaping. The main difference between these two processes is that in shaping the tool reciprocates across the stationary workpiece. Planing motion is the opposite of shaping. Both planing and shaping are rapidly being replaced by milling.

The mechanism used for this process is known as a planer. The size of the planer is determined by the largest workpiece that can be machined on it. The cutting tools are usually carbide tipped or made of high speed steel and resemble those used in facing and turning.

ANALYSIS OF SPLINE PROFILE

INRODUCTION TO SPLINE:

Any one of a series of narrow keys (external splines) formed longitudinally around the circumference of a shaft that fit into corresponding grooves (internal splines) in a mating part: used to prevent movement between two parts, especially in transmitting torque.

For purposes of this article, splines are used in mechanical drive systems. They are found in the rotating mechanisms that we all see daily. Any device that transfers rotary motion from an input to an output most likely uses a spline of some sort. Splines transfer the rotary motion of an input to an output through a mechanical connection, or splined shaft. A splined shaft is one that (usually) has equally spaced teeth around the circumference, which are most often parallel to the shaft's axis of rotation. These teeth can be straight sided, included angle forms (serrations) or involute form. The externally splined shaft mates with an internal spline that has slots, or spaces, formed in the reverse of the shaft's teeth. The rotation of the splined shaft is transferred to the internally splined member, such as a gear or other rotary device.

POINTS TO PONDER:

1)Spline of shafts generally have the following three types of applications:

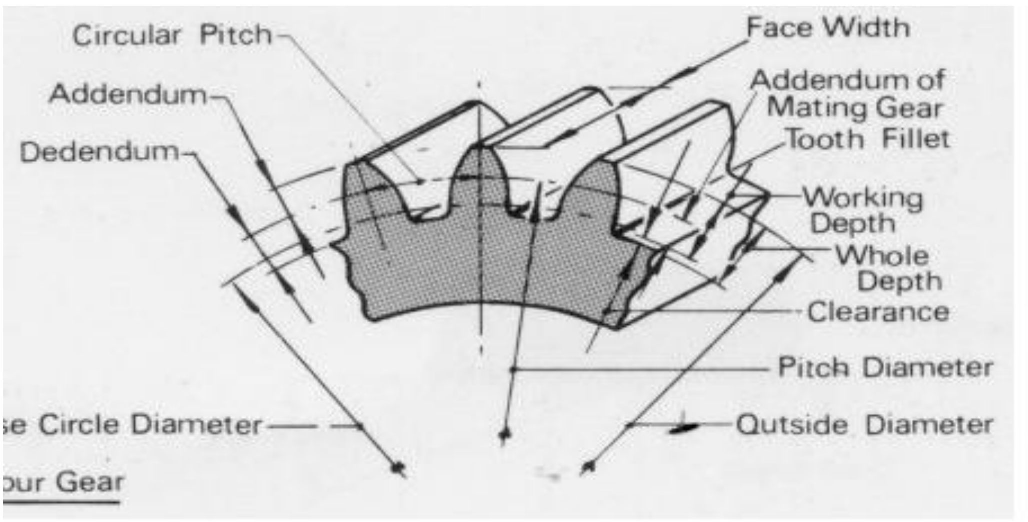
- Coupling shafts when relatively heavy torques are to be transmitted without, slippage
- Transmitting power to floating or permanently fixed gears. Pulleys and other rotating members, and
- Coupling parts that may require frequent removal for indexing or change of angular position.

2) External and internal splines are very extensively used in the automobile, machine tools and other industries. This standard has been prepared to rationalize the production and facilitate interchangeability of external and internal splines.

3) This standard deals with involute sided splines of 30◦ Pressure angle for general engineering purposes. Separate standards on straight sided splines have already been prepared.

GEOMETRY AND NOMENCLATURE OF A SPLINE

DEFINITIONS:



Actual space Width: The circular width on the pitch circle of any single space

Actual tooth thickness: The circular thickness on the pitch circle of any single tooth

Base circle diameter: The diameter of the circle from which involute spline tooth profiles are constructed.

Effective clearance: The difference between the effective space width of the internal spline and the effective tooth thickness at the mating external spline .

Effective error: The accumulated effect of the spline errors on the fit with mating parts

Effective space width of an internal spline: The circular tooth thickness on the pitch circle of an imaginary perfect external spline which would fit the internal spline without Looseness or interference.

Effective tooth thickness of an external spline: The circular space width on the pitch circle of an imaginary perfect internal spline which would fit the external spline without looseness or interference

Error allowance: The permissible effective error.

Involute spline: the spline having teeth with involute profiles.

Machining Tolerance: The permissible variation in actual space width or actual tooth thickness .

Main pressure angle: α_{o} – The pressure angle at the pitch point.

Major diameter: The diameter of the outermost surface of the spline. It is the root diameter of the internal spline or the tip diameter of the external diameter of the external spline.

Minor diameter: The diameter of the innermost surface of the spline. It is the tip diameter of the internal spline or the root diameter of the external spline.

Module (m): The ratio of the pitch circle diameter to the number of spline teeth.

Nominal clearance: The difference between the actual space width of an internal spline and the actual tooth thickness of the mating external spline.

This does not define the fit between the mating members because of the effect of errors.

Pitch circle diameter: The diameter of an imaginary reference circle (Pitch circle) from which all transverse dimensions are derived.

Pitch point: the point of intersection of the spline tooth profile with the pitch circle.

Pressure angle: The acute angle between a line tangent to a profile of the spline and a radial line through the point of tangency. Unless otherwise specified the pressure angle shall mean the main pressure angle.

Profile displacement (xm): The displacement of the base racks either away or towards the reference cylinder and is denoted by “xm”. The former is taken as positive and latter as negative profile displacement.

Spline: A machine element consisting of integral keys (spline teeth) or keyways (spaces) equally spaced around a circle or apportion

Total tolerance: The sum of the machining tolerance and error allowance

TYPES OF SPLINES:

PARALLEL KEY SPLINES:

This type has equally spaced teeth that are straight sided. The teeth on the shaft have an equal tooth thickness at any point measured radially out from the axis of rotation. Conversely, the internal parallel spline has corresponding straight sided spaces. This type of spline is similar to a keyway drive

INVOLUTE SPLINES:

This type has equally spaced teeth, but they are not straight sided. The teeth have an involute form, just like a gear tooth. The teeth do not have the same proportions as a gear tooth; they are shorter in height to provide greater strength. There are no sharp inside corners at the base of the teeth as found in parallel key spline drives. Instead, there is a smooth transition through a radius. This decreases the possibility of fatigue cracking in these areas.

CROWNED SPLINES:

These splines are typically involute. They can be flat root, fillet root, or major diameter fit. The purpose of this type of spline is to allow for angular misalignment between the shaft and mating detail. This is accomplished by "crowning" the male tooth.

SERRATION:

This type of spline has a tooth form that is non-involute. The teeth of the male detail are in the form of an included angle, with the female serration having spaces of the same included angle. Serrations are generally used on smaller diameter drives

HELICAL SPLINES:

These can be either parallel or involute tooth form. The helical spline has a specific lead and a helix angle.In drives where the spline shaft may become torsionally "wound up" (in applications of high torque), a straight spline might lead to drive shaft breakage in areas other than the spline.

ANALYSIS OF SPLINE TYPES:

Involute splines are the predominant form because they are stronger than straight sided splines and are easier to cut and the fit. The external splines can be formed either by hobbing are by a spline shaper. Internal splines can be formed by broaching or a spline shaper. The various simplest method of initially selecting a involute spline based on a shaft dia is to arrive at initial pitch circle dia in module.

Shaft connections based on involute splines are suitable for transferring of hoigh, cyclical and shock torsional moments. Involute spilnes are used for fixed end for sliding connections of shafts with hob.

Advantages of involute splines compared to other splines are higher number of teeth resulting in lower pressures and higher loading capacity of the coupling and more uniform distribution of forces along the perimeter and the disadvatntages include more complicated to engineer to design an involute profile.

SPLINES CUTTING:

Spline cutting is the process of machining internal or external splines (ridges or teeth) onto shafts, gears and other mechanical power transmission components, which mesh with grooves in a mating piece allowing power to be transmitted from one to the other.

Spline cuttings are of two types which are used in industries and they are used in automobile transmission systems.

External spline: An involute spline whose tip surface is external to the root surface.

Internal spline: An involute spline whose tip surface is internal to the root surface.

Splines can be thought of as a series of axial keyways with mating keys machined onto a shaft.

_There are two major types of splines used in industry:-

1) straight-sided splines, and 2) involute splines.

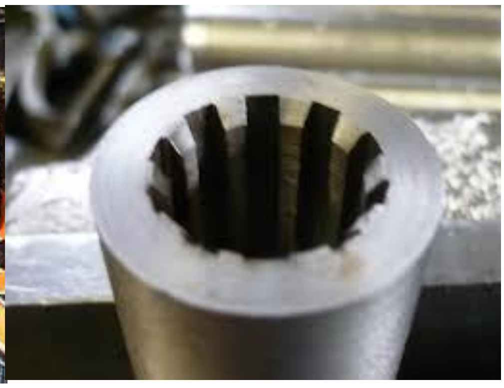
_ Splines provide a more uniform circumferential transfer of torque to the shaft than a key.

Spline cutting is the process of machining internal or external splines (ridges or teeth) onto shafts, gears and other mechanical power transmission components, which mesh with grooves in a mating piece allowing power to be transmitted from one to the other.

The following are the spline cutting operations:

- Broaching
- Hobbing
- Milling
- Shaping

By comparing with the above process, cold form spline rolling is an easier method for producing involute toothed forms.

SPLINE MANUFACTURING PROCESS AND ITS ANALYSIS

Spline cutting is the process of machining internal or external splines (ridges or teeth) onto shafts, gears and other mechanical power transmission components, which mesh with grooves in a mating piece allowing power to be transmitted from one to the other.

The following are the spline cutting operations:

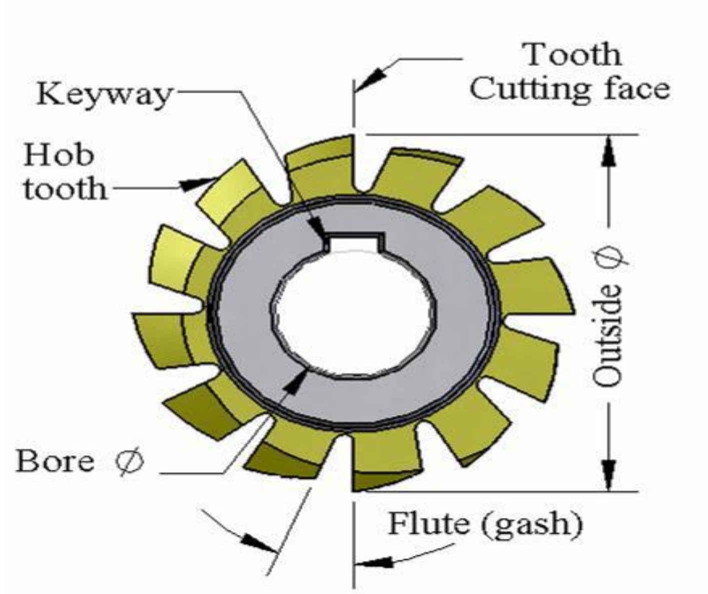
- Broaching
- Hobbing
- Milling
- Shaping

In order to understand variation associated with splines and tooth engagement, the source of the variation must be better understood manufacturing. Previous chapters showed non-random errors associated with the individual splines and the assembly. Repetitive error patterns may originate from manufacturing tools, setup, and other associated processes. There are many processes and tools used in gear manufacturing (see diagram in Appendix B); however, the scope of this work will concentrate on a manufacturing process known as hobbing, with brief consideration given to broaching. Though the exact manufacturing method of the tested splines is unknown, after consulting with a geometrician and the industrial partner, hobbing and broaching seemed like the most likely processes used in manufacturing the external and internal splines, respectively.

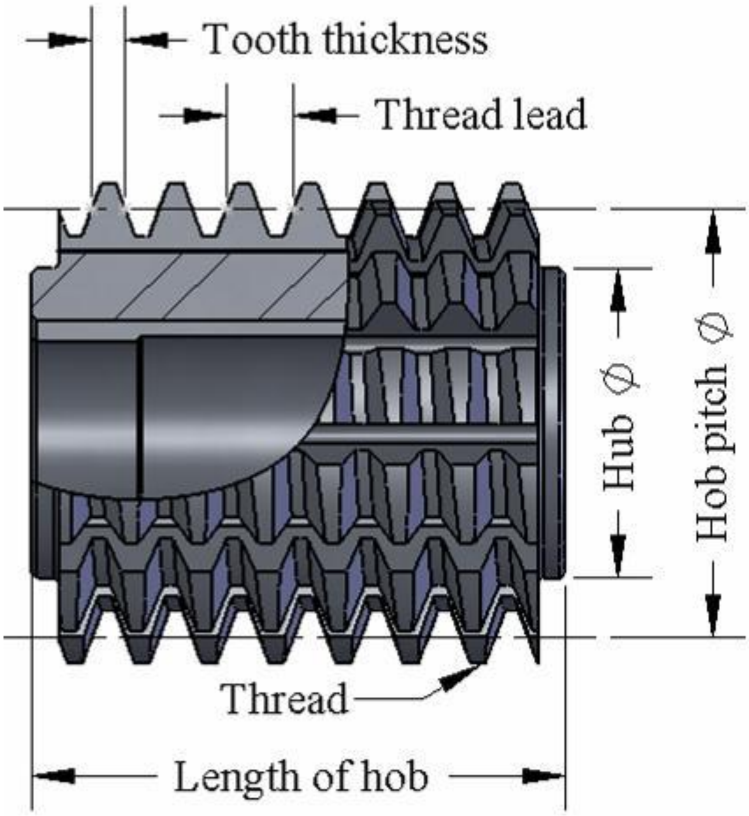
HOBBING:

A hob is a hardened cylindrical cutter for machining gear teeth on a metal gear blank. The hob closely resembles a worm gear with one or more threads that follow a helical path along the length of a cylinder. In order to create the cutting faces on a hob, a series of equally spaced flutes (gashes) are cut along the axial plane. Below fig shows a typical hob from a plane of rotation view and an axial view.

The hobbing process is carried out on special machines, where a hob is positioned by the spline blank and fed axially as it rotates, creating grooves between the splines. The spline blank and hob are separately rotated in a synchronized manner, at a calculated ratio to generate the appropriate number of teeth on the spline blank. The hob is slowly fed parallel to the shaft axis, machining straight grooves as it rotates, transversing the blank, until all of the teeth on spline are generated to the required length. The thread angle of the hob and rotation of the shaft are set such that all of the spline teeth are generated in one pass of the cutter.



PLANE OF ROTATION VIEW OF HOB

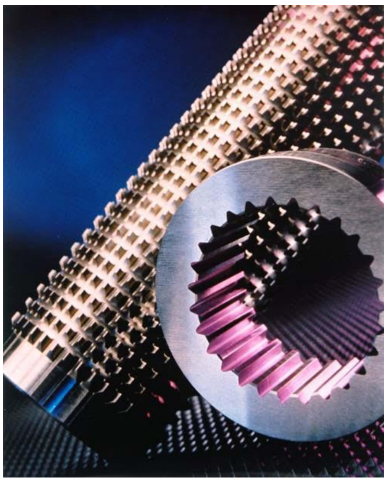


AXIAL PLANE VIEW OF HOB

As the hob rotates, the cutting pattern is repeated again and again. Any error in the hob itself would then leave a repeating error pattern on the spline. This potential source of error patterns is investigated in the sections which follow, to see if they might contribute to the clustered tooth engagement observed in the spline tests.

BROACHING:

Broaching is a machining operation which rapidly forms a contour in a workpiece by moving a cutter, called a broach, entirely past the workpiece. The broach has a long series of cutting teeth that gradually increase in height and are often used to cut internal gear teeth. While broaching produces quite accurate gear teeth, the position of the finished gear teeth with respect to other features of the blank is sometimes difficult to hold. However, the accuracy of a broaching operation can readily be compromised during setup resulting in significant eccentricity error. Furthermore, if a full-topping broach, one that cuts both the tips and roots, is not used, then the error profiles associated with the roots will differ from that of the tips.



MILLING MACHINE:

Milling is the machining process of using rotary cutters to remove material from a workpiece advancing (or *feeding*) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

PROCESS:

Milling is a cutting process that uses a milling cutter to remove material from the surface of a workpiece. The milling cutter is a rotary cutting tool, often with multiple cutting points. As opposed to drilling, where the tool is advanced along its rotation axis, the cutter in milling is usually moved perpendicular to its axis so that cutting occurs on the circumference of the cutter. As the milling cutter enters the workpiece, the cutting edges (flutes or teeth) of the tool repeatedly cut into and exit from the material, shaving off chips (swarf) from the workpiece with each pass. The cutting action is shear deformation; the metal is pushed off the workpiece in tiny clumps that hang together to more or less extent (depending on the metal type) to form chips. This makes metal cutting a bit different (in its mechanics) from slicing softer materials with a blade.The milling process removes material by performing many separate, small cuts. This is accomplished by using a cutter with many teeth, spinning the cutter at high speed, or advancing the material through the cutter slowly; most often it is some combination of these three approaches. The speeds and feeds used are varied to suit a combination of variables. The speed at which the piece advances through the cutter is called feed rate, or just feed; it is most often measured in length of material per full revolution of the cutter.

PLANNING PROCESS:

Inside the mold or die during the casting process.Planing is a manufacturing process of material removal in which the workpiece reciprocates against a stationary single-point cutting tool producing a plane or sculpted surface. Planing is analogous to shaping. The main difference between these two processes is that in shaping the tool reciprocates across the stationary workpiece. Planing motion is the opposite of shaping. Both planing and shaping are rapidly being replaced by milling.

The mechanism used for this process is known as a planer. The size of the planer is determined by the largest workpiece that can be machined on it. The cutting tools are usually carbide tipped or made of high speed steel and resemble those used in facing and turning.

PROCESS CHARACTERISTICS:

- Uses single-point cutting tools
- Involves a reciprocating motion between the tool and workpiece
- Produces plane or sculpted surfaces

PROCESS:

In shaping, the tool is brought into position with the workpiece. The tool then repeatedly moves in a straight line while the workpiece is incrementally fed into the line of motion of the tool, this produces a flat, smooth, and sculpted surface. For shaped pieces the tool reciprocates across the stationary workpiece. The tools are usually tilted or lifted after each stroke. This is done hydraulically or manually in order to prevent the tool surface from chipping when the workpiece travels back across.

SHAPING:

- In electricity generation, maintaining reliable delivery, for example by use of pumped storage hydroelectricity
- Shaping (psychology), the reinforcement of successive approximations to train a type of behavior
- Traffic shaping, internet traffic management
- Shaping (mechanical), a material removal process in which a cutting tool takes mass and shapes a stationary object to produce a sculpted or plane surface.

- Gear shaper, the shaping process used specifically for gear manufacturing
- Shaping (audio), modifications both additive and subtractive that alter the final timbre of the initial audio wave whether this is produced as an acoustic sound wave or an electric signal.

SPECIFICATION OF TK SPLINES AT ES&F

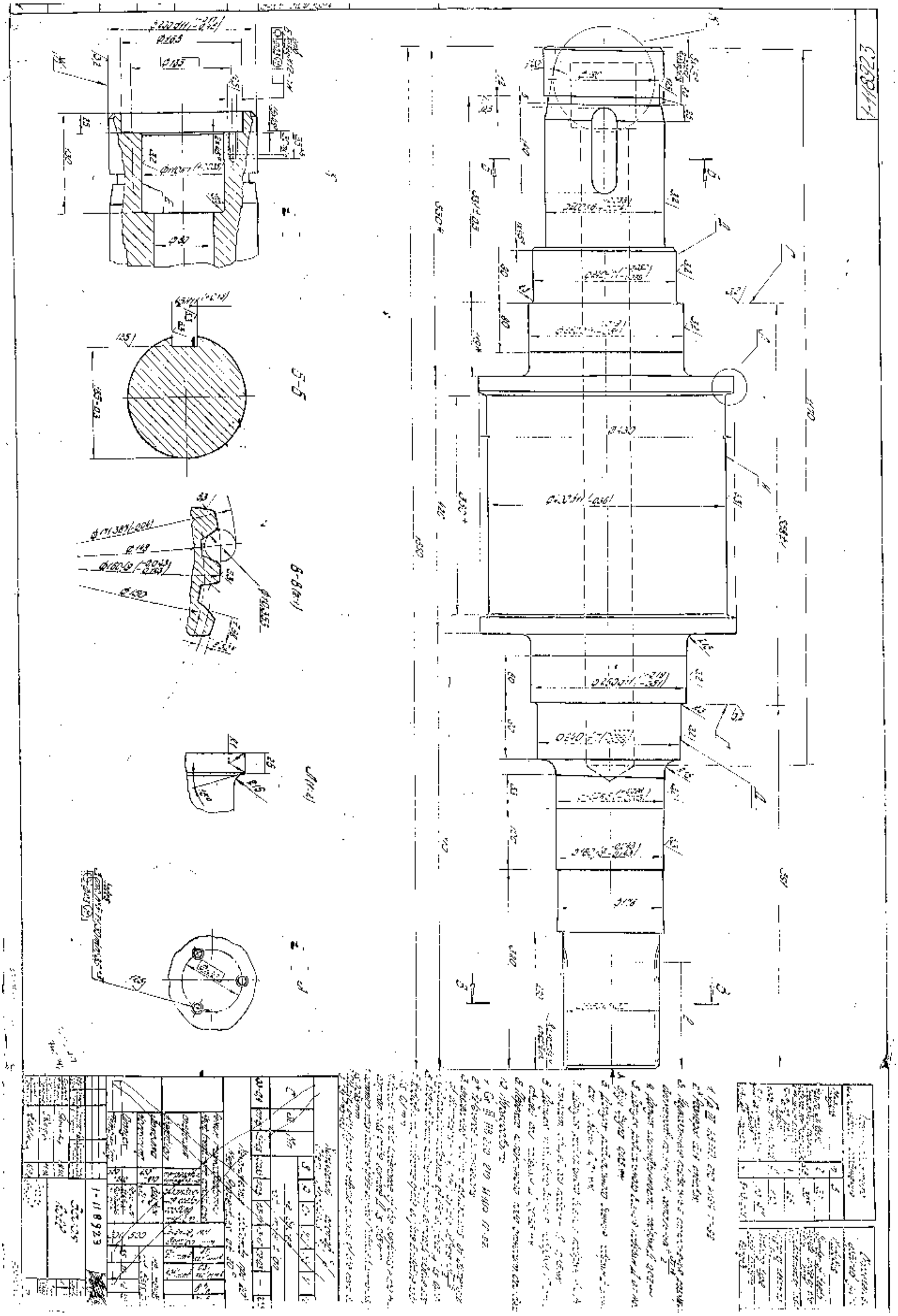
1 CUTTING OF SPLINES BY CHANING THE SIZE OF THE MODULE (m) AS 8 FOR SPLINES MACHINING:

- By modifying splines with key fit, it cannot allow misalignment between TK stand and Intermediate Gearbox (IGB).
- If any misalignment occurs while running of Continuous casting machine, load comes on bearings and lead to failure.
- The key may shear due to high torque transmission.
- Dismantling of IGB from the stand for repair and assembling of IGB to stand is difficult.
- Matching IGB output hallow shaft also to be modified to key fit.
- Due to high temperature environment hollow shaft may expand more and come out of drive roller.
- Existing all rollers to be modified to key fit needs lot of resources.
- All drive rollers are to be modified and corresponding new hollow shafts are to be manufactured with in the plant or procured from the out side parties.
- The cost of implementation of this method is Rs.70, 000/-

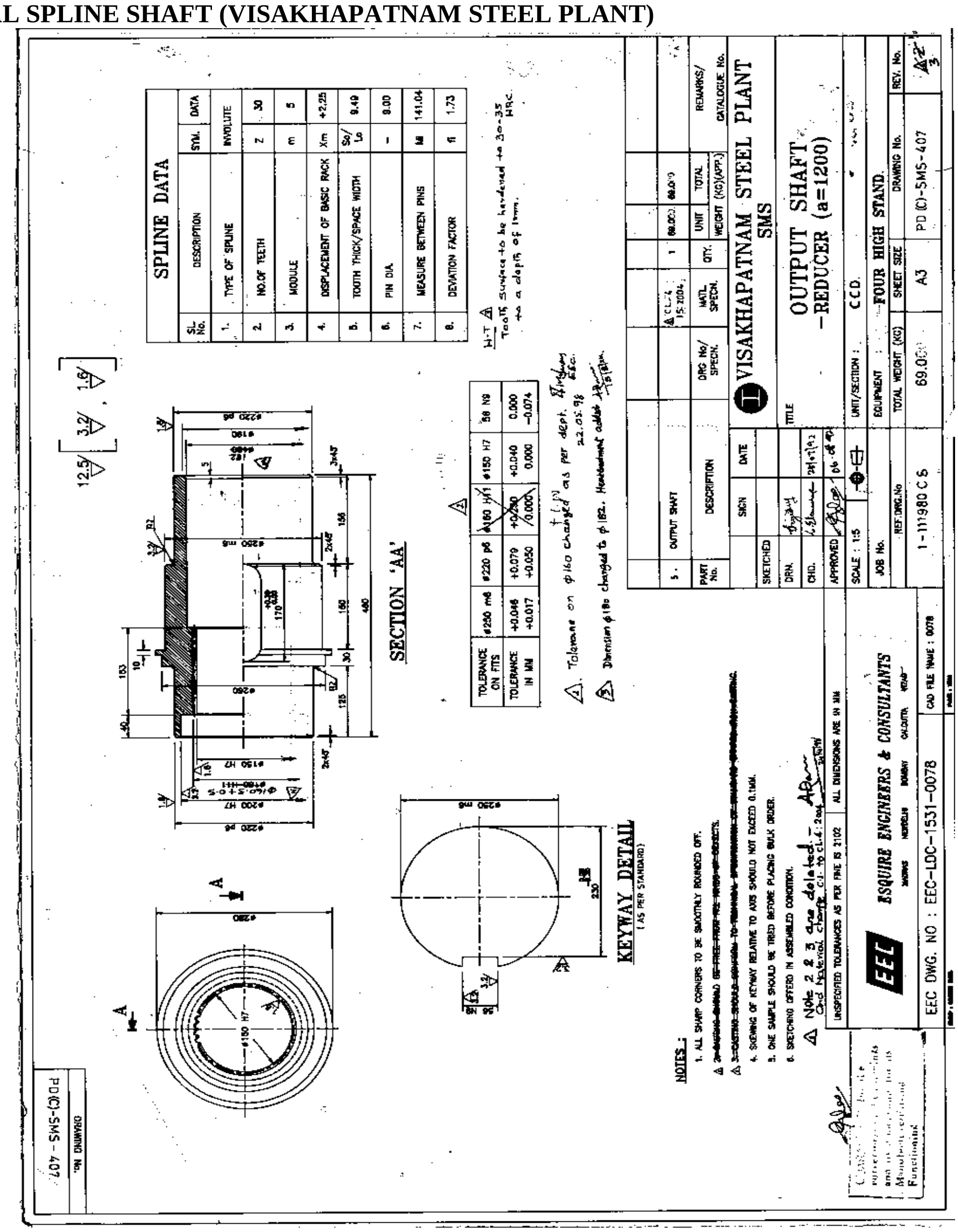
CUTTING OF SPLINES BY CHANING THE SIZE OF THE MODULE (m) AS 8 FOR SPLINES MACHINING (ALTERNATIVE METHOD):

- By complete removal of old spine material by turning on lathe and depositing of metal by welding will give good bonding between the both materials.
- By complete cutting of new splines and subsequent heat treatment will give better life of splines due to hardness.
- By cutting new splines the performance of the power transmission is same as new roller.
- Perfect Involutes profile can be achieved by forming new splines.
- Misalignment of mating teeth can be avoided.
- Due to perfect alignment wear and tear of teeth can be avoided.
- Badly damaged rollers also can be reclaimed by this method.
- Cost of reclamation of each roller is Rs.30,000/-

EXTERNAL SPLINE SHAFT (VISAKHAPATNAM STEEL PLANT)



INTERNAL SPLINE SHAFT (VISAKHAPATNAM STEEL PLANT)



MANUFACTURING METHOD BEING FOLLOWED OF TK SPLINES AT CMS

SPLINE CUTTING ON PLANO MILLING MACHINE:

REQUIREMENTS:

- Vertical attachment
- Bearings –Spherical roller brgs-23048
- Plummer blocks
- Indexing Head
- Coupler for connecting Indexing head and TK roller
- 8 Module, 30 ^{0} pressure angle Involute cutter

VERTICAL ATTACHMENT:

This attachment has been provided by machine supplier to fit into center head of plano milling machine. With this attachment the rotational motion of cutter can be changed from horizontal plane to vertical plane means perpendicular to the table surface. In this attachment stub arbor can be fixed to mount an Involute-milling cutter.

INDEXING HEAD:

The existing indexing head have a live center. To hold the TK roller the indexing head live centre removed and fixed a four jaw chuck with modification. On the back side of four-jaw chuck a threaded bush welded and mounted on indexing head. With this arrangement the TK roller can be rigidly held without slipping.

COUPLER:

A coupler has been made to couple the roller with indexing head. One side of the coupler has a flange with 4 holes of 18mm dia on 210mm PCD. One side of TK roller has 210mmPCD, M16-4 holes to fix the rotary joint for water-cooling. The coupler has been fastened to Tk roller with M16 bolts. The second side of the coupler has 100mm dia step for holding with four-jaw chuck.

PLUMMER BLOCKS:

In this new Spline cutting method the roller is assembled with bearings 23048 and supported by Plummer blocks. Once the TK roller supported by the Plummer blocks with bearings the available indexing head is able to rotate, while indexing because Plummer blocks take the weight of the roller.

PLANO MILLING MAHCINE:

PREPARATION OF TK ROLLER FOR SPLINE CUTTING:

- Stress relieving the old worn out roller
- Heat the roller to 450^0 c at the rate of 50^0c /hour
- Soak the roller for 8 hours
- Cooling the roller to room temperature at the rate of 50^0c/hour
- Under cut the Spline area and remove the old damaged splines completely.

Machine the Spline area to dia 140 mm.

- Built up/metalising the Spline area from dia 140mm to 180 mm with the electrode which should be machinable and gives hardness of HRC 45-50after machining and heat treatment.
- Stress relieving of the built-up roller in order to relieve internal stresses that are developed during welding/ built up.
- Heat the roller to 450^0c @ 50^0c / hour.
- Soak the roller for 8 hours.
- Cooling the roller to room temperature @ 50^0c/hr.
- Machine the Spline step of roller to size 170 f9 tolerances.

TK ROLLER MATERIAL:

40 Ni2 Cr1 Mo28 / EN24

Composition: C 0.35- 0.45%, Si 0.10- 0.35%, Mn 0.40- .70%, Cr 0.90-1.30%, Ni 1.25-1.75%, Mo 0.20-0.35%

DRIVE ROLLER AFTER BUILD UP

DRIVE ROLLER
SPLINE CUTTING IMPLEMENTATION PROCEDURE:

- Stress relieving the TK roller.
- Worn out or damaged splines are completely removed by turning up to Diameter 140 mm on HEC lathe.
- Built up the Spline area up to Diameter 180mm with suitable electrodes
- Stress relieving after built up.
- Turning the built up area to Spline outside diameter 170 f9 tolerance on HEC lathe.
- Bearings 23048 mounted both sides on the bearing seats of TK roller.
- Roller with bearings seated on designed Plummer blocks.
- Total roller assembly placed on Plano Milling Machine. Plummer blocks clamped to machine bed firmly.
- Coupler flange fixed to rotary joint side of TK roller with bolts.
- Hold the other side of coupler step Diameter 100mm with Indexing head modified four-jaw chuck.
- Fixed the vertical attachment to the center head of the machine.
- 8 module, 30^0 pressure angle Involute Milling cutter mounted on Diameter 32mm stub arbor.
- Truing the roller with respect to cutter.
- Cutting the teeth one by one to a length 220 mm as per drawing, by rotating the roller with indexing head.
- After cutting of all 20 teeth, checked the dimensions over pins with micrometer to ensure the correct profile of teeth.
- Checked the teeth matching with IGB out put shaft internal splines.
- Finally heat treatment is carried out to get the desired hardness HRC 45-50.

DRIVE ROLLERS BEFORE AND AFTER CUTTING

DATA ANALYSIS

Design of solid shaft and hollow shaft:-

Power rating of the motor drive(P) = 11 KW.

Speed of the motor (Nm) = 775 R.P.M.

Speed reduction in gear box = 1: 678.44

Let "T" be the torque transmitted by the shaft in N-mm

We know $P = (2\pi N_s T) \div 60$

Where Ns = speed of the shaft.

$Ns = \mathbf{N_m / G} = 775 / 678.44 = 1.14$

$T = (60\times P\times 10^6) \div (2\pi Ns)$ N-mm

$= (60 \times 11\times 10^6) \div (2\times\pi\times 1.14)$

"τ_s be the sheer stress induced in the solid shaft of diameter

Ds= 170 mm

From the torsion equation $T / J = \tau_s / R = G\,\theta / L$ …………(1)

Design of the shaft according to rigidity is neglected because the length of shaft is so small that cannot produce any deflection during working.

Design of shaft according to strength criteria follows

$T / J = \tau_{s / R}$…………………(2)

$\tau_s = (TR)/J$

Where J= polar moment of inertia in mm^4

$J= \pi D^4 \div 32$ for solid shaft.

$J= \pi(D^4 - d^4) \div 32$ for hollow shaft

By substituting the value of "J" in equation (2) we get

$\tau_s = (16 T \div \pi D^3)$ for solid circular shaft

$\tau_h = (16 T D) \div \pi (D^4 - d^4)$ for hollow shaft.

From above analysis

D = diameter of the solid shaft = 170 mm.

τ_s = sheer strength induced in the solid shaft

$\tau_s = 16T\div \pi D^3$

$\tau_s = (16\times 92.1\times 10^6)/ (\pi \times 170^3)$

$\tau_s = 95.47$ N/mm^2

The material of the shaft 40 N 12 CR 1 MO28 (forged quality)

Yield strength of material under tension $\sigma_{yt}= 600$ N/mm^2

Yield strength of material under torsion $\tau_{yt}= 0.5\sigma_{yt}$

$\tau_{yt} = 0.5 \times 600 = 300$ N/mm^2

Consider factor of safety (N) for the shaft as 3

∴ working or allowable shear stress $\tau_w = \tau_{yt} /N$

$\tau_w = 300 \div 3 = 100 N/mm^2$

The induced shear stress in the solid shaft is lower than the allowable shear stress. So design according to strength criteria is safe.

Let "D_o" be the outer diameter of hollow shaft and "D_i" be the inner diameter of the hollow shaft.

Do = 220 mm

Di = 170 mm

"τ_h" be the shear stress induced in the hollow shaft.

Torque transmitted by the shaft $T= 92 \times 10^6$ N-mm.

Speed of the hollow shaft $N_h= 1.14$ Rpm.

Shear stress induced in the hollow shaft (τ_s):

$(\tau_s) = (16TDo) / (Do^4- D_i^4)\pi = 68.38$ N/mm²

Hollow shaft is also manufactured from same material, so $\tau_w = 100N/mm^2$

Therefore, the stress induced in the hollow shaft is less than allowable stress, so design of shaft and the strength criteria is safe.

Design of spline dimensions :

Data taken from Beuro of Indian standards (BIS)

1) Major diameter of internal shaft (d1) = 170 mm.
   Let m=8 , then
2) Profile displacement (xm) =1/2 (d1-m.z-1.1 m)
   The Value shall be from -.05 m to + .045 m = 0.6
3) The number of teeth (Z) = 1/m (d1 - 2 xm – 1.1 m)
   Where "d1" is the major diameter of internal spline
   Z=1/8(170 – 2 × 0.6 – 1.1×8) = 20 teeth.
4) Minior diameter of the internal spline (d2):
   d2 = m.z + 2 xm – 0.9 m = d1 – 2 m
   d2 = 8 × 20 + 2 × 0.6 – 0.9×8 = 170 – 2 × 8
   d2 = 154 mm
5) Major diameter of the external spline (d3) :
   d3 = m.z + 2 xm + 0.9 m = d1 – 0.2 m
   d3 = 8 × 20 + 2 × 0.6 + 0.9×8 = 170 – 0.2 × 8
   d3 = 168.4 mm
6) Minor diameter of the external soline (d4):
   d4 = m.z + 2 xm - 1.1 m = d1 – 2.2 m
   d4 = 8 × 20 + 2 × 0.6 - 1.1× 8 = 170 – 2.2× 8 d4 = 152.4 mm
7) Space width and tooth thickness (lo and s_o):
   lo and s_o = m π /2 + 2 × 0.6 × tan £o
   = (8 × 3.14 ÷ 2) + 2×0.6 × tan 30◦
   = 13.259 mm

Checking the existing dimensions of spline shaft for design Dimensions :

m = 5 ; z = 30 ; Tooth with

d 1 = 160 mm , d 2 = 150mm , Standard size (160×150)

Considering shearing of the spline, the tangential shearing force acting at the mean circumference of the shaft.

F = Area resisting shearing × shear stress

$F = z \times l \times So \times \tau_s$

Torque transmitted by the shaft,

$T = F\times d/2 = Z\times l \times So \times\tau_s \times d/2$

here (d) = Mean diameter of spline shaft= 155mm

$$l = \frac{92.14 \times 10^6 \times 2}{30 \times 10.452 \times 100 \times 155} = 37.9 \quad \text{Say 40 mm}$$

Considering crushing of the spline, the tangential force acting at the circumference of the shaft.

F = Area resisting crushing × crushing stress

$F = Z \times l \times t \times \sigma_c$

Torque transmitted by the shaft,

$T = F \times d / 2 = Z \times l \times t \times d / 2 \times \sigma_c$

$$l = \frac{92.14\times10^6 \times2}{30\times5\times155\times200} = 39.6mm \text{ Say } 40mm$$

for steel material the factor of safety is taking as 5.

L = 5 × 39.6 = 198 mm, Say L = 200 mm

Required length of spline (L) = 200 mm

Existing length of spline(L) = 153 mm

Modified calculation by changing the value of m = 8

Dimensions : m = 8 ; z = 20 ; Tooth with (So) = 13.259 mm

d1 = 170 mm, d 2 = 154mm , Standard size (170 × 154)

Considering shearing of the spline, the tangential shearing force acting at the mean circumference of the shaft.

F = Area resisting shearing × shear stress

$F = Z \times I \times So \times \tau_s$

Torque transmitted by the shaft,

$T = F \times d/2 = Z\times I \times So \times\tau_s\times d/2$

here (d) = Mean diameter = 162mm

Therefore,

Tooth thickness(I) = $(92.14 \times10^6 \times 2) / (20 \times 13.259 \times 100 \times 162) = 42.89$ mm

Considering crushing of the spline, the tangential force acting at the circumference of the shaft.

F = Area resisting crushing × crushing stress

$F = Z \times I \times t \times \sigma c$ Where t = 1 m = 8

Torque transmitted by the shaft,

$T = F \times d / 2 = Z \times I \times t \times d / 2 \times \sigma c$

$I = (92.14\times10^6 \times2) / (20 \times 8 \times 162 \times 200) = 35.54mm$

But higher value of I = 42.89 mm is considered.

For steel material the factor of safety is taking as 5.

L = 42.89 × 45 = 214.45 mm, Say 220 mm

Length of spline required (L) = 220 mm

Checking for change in induced shear stress

$T = F \times d/2 = Z\times l \times So \times\tau_s\times d/2$

$\tau_s = (92.14\times10^6 \times2) / (20 \times220 \times 13.259 \times 162) = 19.498 N/mm^2$

% Reduction in induced stress = 95.47 - 19.49 = 75.98 N/mm^2

= (75.98 / 95.47) × 100 = 79.58%

Checking for change in shear area

Existing shear area = 30×142 × 10.452 = 44839 N/mm^2

Modified shear area = = 20×220× 13.259 = 58339.6 N/mm^2

% Increase in shear area = 58339.6 – 44839.08 = 13500.52

= (13500.52 / 58339.6) × 100 = 30.1%

Checking for change in length

Existing nlength = 153mm (Net length 143mm)

Modified length = 220mm

% Increase in length = 220 -143 = 77mm =(77/220) = 35%

Comparison of spline data after implementation.

Table

S.No.	Description	Symbol	Existing	Modified
1.	Type of spline	Involute		
2.	Number of splines	Z	30	20
3.	Module	M	5	8

4.	Profile displacement	Xm	+2.25	+0.6
5.	Space width /Tooth thick in mm	Lo/So	10.452	13.259
6	Pin diameter in mm (External spline)	Da	10	16
7.	Pin diameter in mm (internal spline)	Di	9.00	14.00
8.	Measure between pins (External) in mm	Ma	170.00	186.514
9.	Measure between pins (Internal) in mm	Mi	141.04	140.681
10.	Deviation factor	Fi	1.73	1.95
11.	Pressure angle	A	30	30

Results of analysis:

S.NO	DESCRIPTION	EXISTING SYSTEM	MODIFIED SYSTEM
1.	Allowable shear stress of the material	100 N/mm²	100 N/mm²
2.	Induced stress	95.47N/mm²	19.49N/mm²
3.	Shearing area	44839.08mm²	58339.6mm²
4.	Length of Spline	142	220
5.	% Reduction in induced stress	Not applicable	79.58%
6.	% Increase in shearing area	Not applicable	30.1%
7.	% Increase in spline length	Not applicable	35 %

From the reference - table..1

Module (m)	d_0	Internal Spline (in mm)			External Spline (in mm)		
		d_1	d_2	d_3	d_4	d_5	d_6
5	150	160	150	159	149	159.12	149.88
8	160	170	154	168.4	152.4	168.52	153.89

Designation of Spline

170×154×20×8eb External involute spline

170×154×20×8HE internal involute spline

Designation of Spline assembly

170 H7/h6 × 154 ×20 × 8HE/8eb

By the reference of table……3

Tolerance of tooth thickness (So) for External ....e

$+ 0.175$

$= 13.00^{+0.119}$ mm.

Tolerance of space width (lo) for Internal …..$H_{+0.315}$

$= 13.00^{+0.259}$ mm.

ADVANTAGES:

- Lower wear of sliding couplings Suitable also for cyclical torsional moments
- Easy assembly and disassembly of the coupling.
- Higher number of teeth resulting in lower pressures and higher loading capacity of the coupling.
- More uniform distribution of forces along the perimeter
- High accuracy of production similariy as with accurate gears

DISADVANTAGES:

- More complicated to engineers to design a involute profile curve.
- Higher production cost than couplings with keys.

CONCLUSION

Tooth profile in spline cutting is complex and difficult to predict due to variation and errors that arise from manufacturing tools and processes. Since the design of involute splines and their manufacturing requires considerable knowledge not only the basic properties of involute profile, but also various other elements which effect the spline fit. It can be concluded that, the involute profile effected by the designations of profile that is module, pitcc circle dameter and number of teeth. As we observed from the manufacturing process if we increase or decrease the standard pressure angles the width of the teeth increases and the equal load carrying capacity decreases due to this some small errors occurs. Due to very small errors, spline cutting teeth do not engage simultaneously, but rather tend to get engage sequentially. As a result of sequential engagement, the first tooth pair to engage will carry more load than the succeeding tooth pairs and will therefore deflect the most and fails sooner. In order to better understand tooth profile and manufacturing operations, this thesis has extensively studied and analysed.

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