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Review on Design Basics of Industrial Application Gear Box

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Abstract : An industrial gearbox is defined as a machine for the majority of drives requiring a reliable life and factor of safety, and with the pitch line velocity of the gears limited to below 25 m/s, as opposed to mass produced gearboxes designed for a specific duty and stressed to the limit, or used for very high speeds etc., e.g. automobile, aerospace, marine gearboxes. A gear box is an mechanical device that is used for speed & torque conversions from prime mover to output shaft. As the speed of shaft increases the torque transmitted decreases and vice versa. To the competent engineer, the design of a gear unit, like any other machine, may seem a fairly easy task. However without experience in this field the designer cannot be expected to cover all aspects of gearbox design. The purpose of this paper is to review the basic design for an industrial gearbox. It should help the researcher not familiar with gear boxes, lay out a reliable working design. And it is intended for the reader to use his own experience in selecting formulae, stress values etc., for gearbox and components.

Keywords: Gear Box, Design, Types.

I. INTRODUCTION

Selecting a gearbox can be quite difficult. Customers have a variety of gearboxes to choose from that are capable of fulfilling diverse requirements. A wrong decision could result in the purchase of a more ex- pensive gearbox. The power transmission industry may need a gearbox that will support overhung loads while the motion control or servo industry may need a gearbox that will handle dynamic motion.

One of the first problem areas for sizing arises from sizing to the motor versus sizing to the load. Sizing to the motor may be simpler and result in a gearbox that works, but it will result in the purchase of a larger gearbox than is needed. This gearbox will also be overqualified for the application. However, sizing to the load will ensure a gearbox fits the application and is more cost-effective as well as potentially a smaller footprint.

1.1 GEARBOX

A gearbox is a mechanical device utilized to increase the output torque or change the speed (RPM) of a motor.

The motor's shaft is attached to one end of the gearbox and through the internal configuration of gears of a gearbox, provides a given output torque and speed determined by the gear ratio. The gear box consists of one or more gear pairs of same or different type.

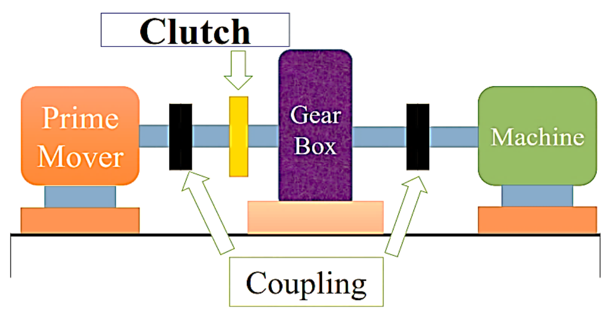

Figure 1.1.1. Gear Box

Gearboxes, also known as enclosed gear drives or speed reducers, are mechanical drive components that can control a load at a reduced fixed ratio of the motor speed. The output torque is also increased by the same ratio, while the horse- power remains the same (less efficiency losses.). For example, a 10:1 ratio gearbox outputs approximately the same motor output horsepower, motor speed divided by 10, and motor torque multiplied by 10.

II. Necessity of Gear Box in an Automobile

1. The gear box is necessary in the transmission system to maintain engine speed at the most economical value under all conditions of vehicle movement.
2. An ideal gearbox would provide an infinite range of gear ratios, so that the engine speed should be kept at or near that, the maximum power is developed whatever the speed of the vehicle.

III. Function of Gear Box

1. Torque ratio between the engine and wheels to be varied for rapid acceleration and for climbing gradients.
2. It provides means of reversal of vehicle motion.
3. Transmission can be disconnected from engine by neutral position of gear box
4. To increase the torque.
5. To increase the speed.
6. To convert the single input speed to multiple output speeds.

IV. Type of Gear Boxes

A. According to relative position of input and output shafts: Parallel Axes Gear Boxes, Co- Axial Gear Boxes, Intersecting Axes Gear Boxes

B. Non-intersecting and perpendicular Axes Gear Boxes:

a) According to number of stages : Single Stage Gear Boxes, Multi-stage Gear Boxes

a) According to number of speed ratio : Single speed gear boxes, Multi speed gear boxes

The multi speed gear boxes are further classified into three types: Sliding mesh gear boxes, Constant mesh gear boxes, Synchromesh gear boxes

4.1 Sliding Mesh Gear Box :

It is the simplest and oldest type of gear box. The clutch gear is rigidly fixed to the clutch shaft. The clutch gear always remains connected to the drive gear of countershaft. The other lay shaft gears are also rigidly fixed with it. Two gears are mounted on the main shaft and can be sliding by shifter yoke when shifter is operated. One gear is second & top speed gear and the other is the first and reverse speed gears. All gears used are spur gears. A reverse idler gear is mounted on another shaft and always remains connected to reverse gear of counter shaft.

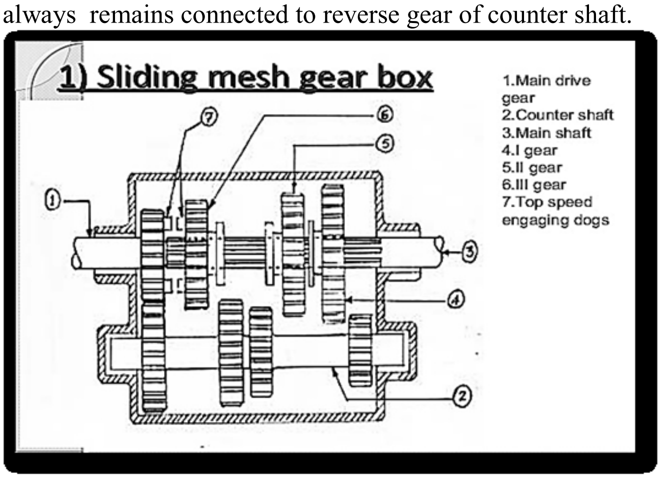

Figure 4.1 Sliding Mesh Gear Box

4.2 Constant Mesh Gear Box :

In this type of gearbox, all the gears of the main shaft are in constant mesh with corresponding gears of the countershaft. The gears on the main shaft which are bushed are free to rotate. The dog clutches are provided on main shaft. The gears on the lay shaft are, however, fixed. When the left Dog clutch is slide to the left by means of the selector mechanism, its teeth are engaged with those on the clutch gear and we get the direct gear. The same dog clutch, however, when slide to right makes contact with the second gear and second gear is obtained. Similarly movement of the right dog clutch to the left results in low gear and towards right in reverse gear. Usually the helical gears are used in constant mesh gearbox for smooth and noiseless operation.

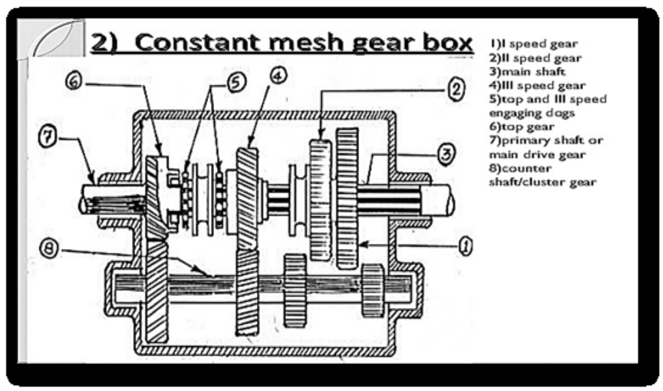

Figure 4.2.Constant Mesh Gear Box.

4.5 Synchromesh Gearbox :

This type of gearbox is similar to the constant mesh type gearbox. Instead of using dog clutches here synchronizers are used. The modern cars use helical gears and synchromesh devices in gearboxes, that synchronize the rotation of gears that are about to be meshed synchronizers. This type of gearbox is similar to the constant mesh type in that all the gears on the main shaft are in constant mesh with the corresponding gears on the lay shaft. The gears on the lay shaft are fixed to it while those on the main shaft are free to rotate on the same. Its working is also similar to the constant mesh type, but in the former there is one definite improvement over the latter. This is the provision of synchromesh device which avoids the necessity of double-declutching. The parts that ultimately are to be engaged are first brought into frictional contact, which equalizes their speed, after which these may be engaged smoothly.Figure.4 shows the construction and working of a synchromesh gearbox.

In most of the cars, however, the synchromesh devices are not fitted to all the gears as is shown in this figure.They are

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fitted only on the high gears and on the low and reverse gears ordinary dog clutches are only provided. This is done to reduce the cost.

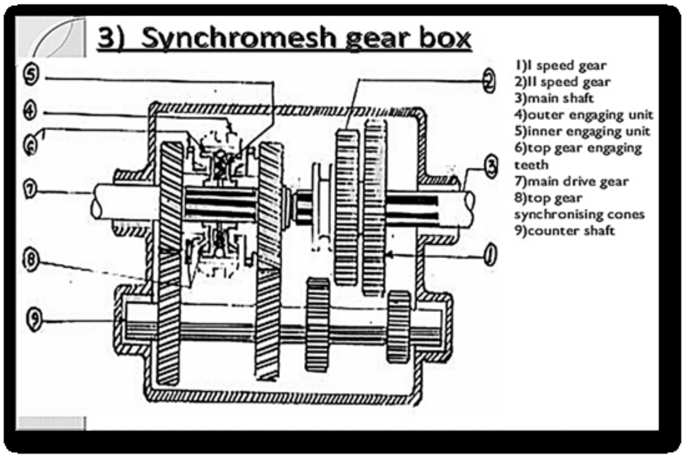

Figure 4.5 Synchromesh Gearbox

V. Basic consideration in Selection of Gear Box

Before starting the preliminary design, the following factors must be known :

- The type, powers and speeds of the prime mover.
- The overall ratio of the gearbox.
- The types of unit required – parallel or angled drive.
- Any abnormal operating conditions.
- The disposition of the input to output shaft.
- The direction of rotation of the shafts.
- Any outside loads that could influence the unit, e.g. overhung loads, brakes, outboard bearing etc.
- The type of couplings to be fitted.
- Application
- Space required

VI. Selection of Gear Box

For Good performance of Gear Box, The right selection is very important. The Gear Unit Selection is made by comparing actual transmitted loads with catalogue ratings are based on standard set of load conditions, which invariably changes for different conditions. Therefore service factor must be used to calculate a theoretical transmitted load or equivalent load, before comparing the same, apply the formula :

Equivalent Load = Actual Load x Service Factor

6.1 Mechanical Ratings :

Mechanical ratings measure capacity in terms of life and / or strength, assuming 10 hours per day continuous running under uniform load conditions, when lubricated with an approved oil and working at a maximum oil temperature of 100°C for normal application lubricant equivalent to ISO VG 320 should be used. When a unit transmits less than catalogue rating, its life is increased. If running time is more than 8 hours per day a service factor from Table of Mechanical Service Factor ensure selection of a unit which transmits less than the catalogue rating, its life is thus increased consistent with the increased daily running time. Catalogue ratings allow 100% overload at starting, braking or momentarily during operation, up to 10 times per day. The unit selected must therefore have a catalogue rating equal to, or greater than half the maximum overload. If the unit is subjected to sustained overloads or to shock loads, these must be reflected in the chosen service factor. If overloads can be calculated or estimated then the actual loads should be used instead of a factor.

6.2 Thermal Ratings :

Thermal ratings measure the unit's ability to dissipate heat. If they are exceeded the lubricant may overheat and break down, with consequent life failure. Both mechanical and thermal ratings are given on next page. Thermal ratings are effected by ambient temperature and not by mechanical consideration such as increased running time or shock loads. Catalogue ratings assume 20°C running temperature, the oil temperature then rising as the unit transmits power and generate heat.

If the ambient temperature is more than 20° C, a lower temperature rise is allowed therefore less power may be transmitted. Similarly in cooler temperatures the thermal ratings may be exceeded. When selecting unit use a service factor from Table of Thermal Service Factor to calculate equivalent loads.

For unit sizes 40 to 200, the relevant mechanical and thermal service factors are selected from tables and whichever is higher is applied to find out the equivalent output power and output torque. For unit size 200 to 350, mechanical service factor should be applied to mechanical ratings and thermal service factor should be applied to thermal ratings. Higher of these should be considered for selection of the unit.

Thermal ratings assume fan cooling which is standard feature of all Speed Reduction Units.

For intermittent running with ample cooling time during rest periods, thermal ratings may be exceeded without overheating and since fan it ineffective, it can usually be removed.

6.3 Service Factor

Before sizing an application, the customer should determine the service factor. Service factor can be

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generally defined as an application's required value over the rated value of the unit. Service factor should be determined for conditions such as non-uniform load, hours of service, and elevated ambient temperature.

How would one interpret a service factor? A service factor of 1.0 means a unit has just enough capacity to handle the application. There is no tolerance for additional requirements, which could cause the gearbox to overheat or fail. For most industrial applications, a service factor of 1.4 is adequate. This service factor signifies that the gearbox can handle 1.4 times the application requirement. If the application requires 1,000 inch-pounds, the gearbox would be sized to handle 1,400 inch-pounds. Different factors will affect how much service factor should be used in a given application. The changes to service factor depend on the manufacturer. Please examine the manufacturer's specifications.

Table 6.3 Suggested service factor based on service class

Service class	Service factor	Operating conditons
I	1.25	Moderate shock - not more than 15 min. in 2 hr. Uniform load - not more than 10 hrs. per day
II	1.40 1.50	Moderate shock - not more than 10 hrs. per day Uniform load - more than 10 hrs. per day. Heavy shock - not more than 15 min. in 2 hr. Moderate shock - more than 10 hrs. per day
III	1.75 2.00	Heavy shock - not more than 10 hrs. per day Heavy shock - more than 10 hrs. per day

6.4 Ambient Temperature And Environment

Higher ambient temperatures increase internal pressure, which will require an increase to the service factor used. High or low temperatures can require different seal materials and lubrication viscosities.

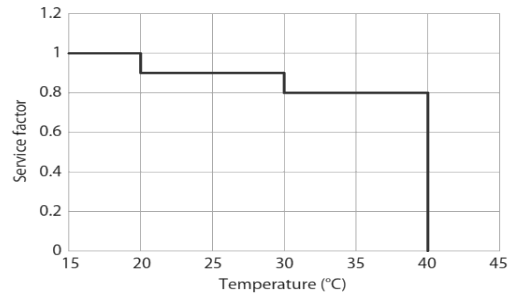

Figure.6.4 Graph for Ambient temperature vs. Service factor

The environment the gearbox will operate in is also an important consideration for sizing. Harsh environments can increase wear on the unit. Dusty or dirty environments often require special material to prevent corrosion or bacteria growth. Food or beverage plants require specific FDA compliant coatings and oil. Vacuum environments will require special grease and heat dissipation considerations, since there will be no air for cooling. Failure to account for these environmental features can result in a gearbox that cannot support the application properly. All of these aspects must be considered when sizing a gearbox.

6.5 Shock Load or Type of Load

High shock or impact loads can cause increased wear on the gear teeth and shaft bearings. This wear could cause premature failure if not accounted for when sizing. These loads will require an increased service factor. Uniform loads are loads that remain constant during the application, while non-uniform loads change during the application. Non-uniform loads, even if small, will require a higher service factor than uniform loads. An example of a uniform load would be a conveyor with a consistent product amount riding on it. A non-uniform load would be any sort of intermittent cutting application. This intermittent cutting force causes a periodic increase in the torque on the gearbox, which is a non-uniform load.

6.6 Output Style or Mechanism

Output mechanisms include a sprocket, pulley, or toothed pinion, to name a few. Different output configurations, such as double output shaft or shaft mounted bushing, will decrease how much overhung load the unit is rated for. Different output mechanisms add different shaft loads that must be considered. most mechanisms will cause high radial load, but things like helical gearing can also cause an axial load. These outputs could require different bearings to account for the increased radial or axial load.

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6.7 Output Shaft or Hollow Bore Size

When sizing an application, the output shaft and bore size must meet customer requirements. These could include a stainless output on the unit, and whether it has a keyed or keyless shaft, a keyed or keyless hollow bore, or a flanged output combined with any of the previous. Getting the correct bore size on a unit may force the customer to purchase a larger gearbox or a different style of gearbox to fit their current shaft. In some instances, the customer can modify their shaft to use the most cost-effective unit while providing an optimal solution.

6.8 Housing Styles

It is also important when selecting a gearbox to consider how it will mount. A unit could have mounting feet, a flange on the output, or just basic tapped holes on one or more sides. These housing styles could limit how a unit is mounted so having a variety of options could prevent custom frames or brackets from being needed. For example, having tapped holes on the bottom face of the unit would prevent the need for a special L-bracket to mount around the output.

6.9 Power Transmission:

Some elements that affect the sizing process are industry specific. For the power transmission industry, output rpm, motor horsepower and frame size, and overhung load all impact the application calculations.

a) Output RPM

The customer must determine the ratio needed for the gearbox to operate, or provide input/output speed and operating hertz (Hz) for calculations. The standard is a 1750 input rpm at 60 Hz. Any changes will need to be specified when sizing as it will change the ratio calculation. Failure to account for changes will result in a gearbox that does not match the customer's requirement.

b) Motor HP and Frame Size

The gearbox size and input option must be determined before calculating the service factor. Once the gearbox is sized, use the required HP to compute the actual service factor. Large HP motors generate heat that can adversely affect the reducer's mechanical ratings. This reduced rating, based on the increased heat, is known as the Thermal Capacity of a reducer, and must be considered when using large motors.

c) General Shaft Load

The sizing must verify that the load will not damage the gearbox. The force, measured in pounds, that the output shaft is capable of sustaining is known as the Overhung Load rating. If the rating is less than the application, the speed reducer will be damaged.

6.10 Motion Control:

For the servo industry, input speed, inertia, dynamic torque motion, specific shaft loads, and motor shaft diameter affect the sizing process.

a) Input Speed

Input speed should not exceed the gearbox ratings or premature seal wear will occur due to increased pressure. Input speed can be accidently increased if there is an output mechanism with a ratio that is not considered when sizing, which is another reason why specifying any output mechanisms is so important.

b) Inertia

An inertia mismatch of less than 10:1 is desired for fine controlling of the output. This is important to obtain the high accuracy needed for some applications. reducer size and ratio are main influences from the gearbox on inertia. Control engineers may request smaller mismatches or even specific amounts. Often a motor is chosen for its dynamic capabilities, not for its torque. It is common to use a motor with much more torque than needed for the application due to its increased rotor inertia. This allows for better tuning of the application because of a lower inertia mismatch. When doing this, it is important to limit the output torque in the motor to prevent breaking the gearbox.

c) Dynamic Motion

Cyclic motion may require using a higher service factor than continuous motion. This is because constant starts and stops cause additional wear on the gear teeth and seals. Cyclic reversing, which is constant back and forth motion between two points, requires an even higher service factor than cyclic or continuous.

d) Specific Shaft Loads

Radial, axial, and moment shaft loads must be checked against the unit's ratings. Failure in doing this could result in a broken shaft or damage to the bearings or gear teeth. Generally, the same service factor is applied to these ratings to determine an appropriately strong gearbox. Additional bearing types can increase these ratings if the application needs

e) Motor Shaft Diameter Or Length

The motor shaft must fit in the unit, and the shaft must be long enough for full engagement with the coupling. Without full engagement, input slippage could occur. While this will not affect the service factor needed, it is important to consider in order to avoid problems mounting the motor. Some manufacturers have a large input design allowing the reducer to accommodate the larger motor without increasing the unit size.

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6.11 Gear Ratio

Gear ratio is nothing but the correlation between the numbers of teeth of two different gears. Commonly, the number of teeth of a gear is proportional to its circumference. This means the gear with larger circumference will have more gear teeth, therefore the relationship between the circumferences of two gears can also give an accurate gear ratio. E.g. If one gear has 36 teeth while another has 12 teeth, the gear ratio would be 3:1.

Table 6.11 .Different gear ratio.

Sr.No	Gear Type	Ratio
1	Single stage spur / Helical	6:1
2	Two stage spur / Helical	35:1
3	Three stage spur / Helical	200:1
4	Bevel gear	6:1
5	Worm gear	70:1

6.12 Basic Size and Cost

The two types of tooth that can be used for both parallel and angled drives are straight or helical (spiral). Spur gears are easier to manufacture and inspect than helical gears, and they can be rectified more easily at the assembly stage if required. The main disadvantage of a spur gear compared with a helical, is in the tooth engagement process. The whole of the spur tooth enters engagement at the same time, and therefore any pitch (spacing) error will cause interference and noise. Spur gears are generally used for pitch line speeds below 10 m/s in drives that are not loading the teeth to their maximum allowable limits. They are also used where gears are required to slide axially in and out of mesh.

Helical gears can be manufactured on most modern gear cutting machines. They will probably take longer to machine because of the relative wider face, and hence be more expensive than an equivalent size spur gear.

Double helical gearing has the same characteristics as the single helical but with the elimination of end thrust, as the two helices producing the thrust are cut with opposite “hands”. This type of gearing is also useful where the pinions are of small diameter, as the equivalent face to diameter ratio is only half that of a similar net face single helical gear.

Bevel gears are used for drives requiring the input shaft to be at an angle, usually 90° to the output shaft. They can be cut with either straight teeth, where the same comments as for spur gears apply, or they can be cut spiral which correspond to the helical type of parallel gearing.

Gearboxes can be designed using the same type of gearing throughout, or a combination depending on powers, speeds and application.

6.13 Speed Reducer Selection.

(1) Service Factor

From Table 1 select the service factor applicable to the drive.

(2) Design Power

Multiply the absorbed power (or motor power if absorbed power not known) by the service factor chosen in step (1).

(3) Unit Selection

Using the value from step (2) refer to the power rating standard tables and select the correct size of unit.

(4) Output Speed & Pulley Diameters

Read across from the chosen output speed to obtain both driving and driven pulley pitch diameters, groove section and the appropriate number of belts.

(5). Centre Distance & Hub Bore Size

Belt length and centre distance can be found by give data. Refer to the output hub dimensions given table.

(6). Gearbox Input Shaft Speed

Multiply the gearbox output speed by the exact gear ratio to obtain the gearbox input shaft speed.

VII. Conclusion

To achieve the best gearbox solution, customers should size from the load. This will ensure they receive cost- effective solution that fits the application. The service factor, environment, ambient temperatures, shock load, output style, and hours of service are all important aspects for sizing. The more information the customer provides, the more accurate the sizing process. This will ultimately yield a solution that matches the customer’s requirements! There are numerous sizing programs available that can help determine what gearbox is most appropriate for your application.

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