

Gearhead Construction and Use

- Spur Gear Type Gearheads
- Direction of Rotation
- Planetary Gears

Spur Gear Type Gearheads

Spur gear type gearheads are probably the best possible choice for relatively low torque applications. They tend to be quieter in operation and have a relatively low amount of internal friction as well. Engineers designing high accuracy positioning servos are occasionally surprised to find that many of the small gearhead series supplied by MicroMo use non-integer gear ratios. This fact is often discovered after the engineer has repeatedly tried to reconcile motor encoder counts with gearhead shaft position only to find a small but persistent position error. At first glance, the use of non-integer gear ratios appears to have no apparent purpose (with the possible exception of frustrating servo designers). There is a fundamentally sound reason for designing gearheads with such gear ratios, however, and the servo designer who has sufficient information will generally have no problems using them.

In the process of cutting gears, there is a small but inevitable error in tooth profile that is introduced by such process parameters as tool-wear. The profile error usually manifests itself in the last tooth cut on a particular gear blank. Depending upon the machine set-up and extent of tool wear, the material remaining on the gear blank for last tooth may be more or less than required to form a perfect tooth profile. As a result, an error may be introduced in the profile of the last tooth.

Assume, for example, that gear A (10 teeth) is driving gear B (30 teeth) to achieve an exact 3:1 reduction ratio (see Figure 23). The shaded tooth on gear A will repeatedly mesh with only the three shaded tooth pairs on gear B. If the shaded tooth on gear A has an incorrect profile, the adversely affected gear teeth will be limited to those same six shaded teeth on gear B (assuming bi-directional rotation). These six gear teeth will rapidly wear since they mesh only with a gear having an incorrect profile. While the damaging effects to the teeth on gear B may be very small for each time that the gears mesh, they are repeated on each rotation. Thus the cumulative effect is to promote uneven wear on gear B. As a result, the gear pass will not only generate excessive audible noise but also have a limited service life.

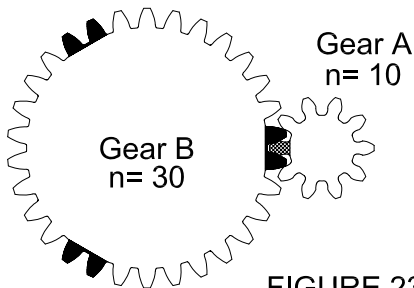


FIGURE 23

The situation is dramatically improved if gear wear can be distributed uniformly among all gear teeth. Figure 24 shows a gear pass similar to that of Figure 1 except that gear A now has nine teeth and gear B 31 teeth, resulting in a gear ratio of 31/9, or 3.44444... :1. The gear tooth with the “defective profile” on gear A is shaded.

The spaces between gear teeth on gear B are labeled with numbers designating where the “defective” profile will mesh for each rotation of gear B up to nine rotations. If the gears A and B are meshed as shown and A is rotated (driving B), the defective tooth profile will mesh with B at those points marked “1” during the first revolution of B, points marked “2” during the second revolution of B, points marked “3” during the third revolution of B, etc. After nine rotations of gear B, the cycle repeats itself. Therefore, the defective tooth profile will mesh with any given tooth on gear B only once in every nine revolutions. In addition, the defective tooth on A will mesh with every tooth on B during those nine revolutions. The net result is that wear attributable to a profile error on A will be equally distributed among all gear teeth on B.

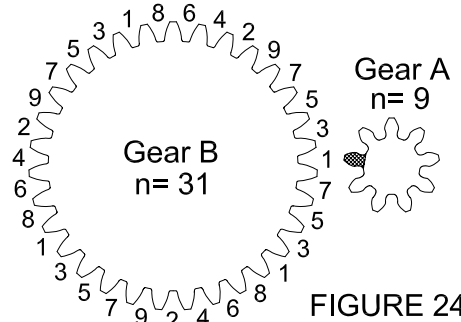


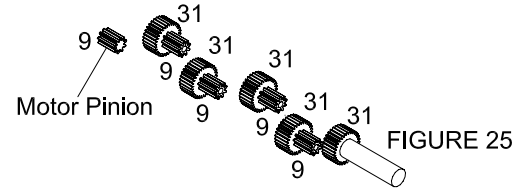
FIGURE 24

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Having described this method of improving gear performance and service life, the next step is to explain how it is put into practice in gearheads. Figure 25 illustrates a typical construction for a gearhead having a specified ratio of 485: 1. Counting the mesh of the nine tooth motor pinion to the 31 tooth input gear, the final gear ratio is obtained by using five 31/9 gear passes. Therefore the exact ratio for the gearhead is given by:



$$(31/9)^5 = (3.4444)^5 = 484.8372:1$$

For the general case of a gearhead having n 31/9 reductions, the exact gear ratio is given by:

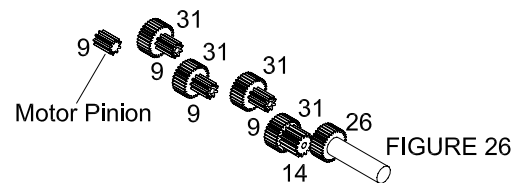
$$\text{ratio} = (31/9)^n$$

The gear ratio can be changed by adding or removing 31/9 gear passes to the input end of the gearhead. Using this technique of multiple 31/9 gear passes, the following gear ratios are produced

Specified Ratio	Number of 31/9 passes	Exact Ratio
11.8:1	2	11.8642
41:1	3	40.8656
141:1	4	140.7592
485:1	5	484.8372
1670:1	6	1669.9948
5752:1	7	5752.2041
19813:1	8	19813.1476
68245:1	9	68245.2861
235067:1	10	235067.0967

*results rounded to four decimal places

Additional gear ratios can be added by changing the number of teeth on the output shaft gear to 26 and the number of teeth on the gear driving it to 14. If the analysis shown in Figure 2 is repeated using a 26/14 ratio, it will be seen that the meshes for any particular tooth on the driving gear are, once again, equally distributed among the teeth of the driven gear. By introducing the 26/14 ratio at the high torque end of the gearhead as shown in Figure 26, an additional series of gear ratios is generated. The resulting ratios are given by:



$$\text{ratio} = (n \times 31/9) \times (26/14)$$

where n = the number of 31/9 gear passes.

The gearhead ratios which can be generated with the addition of the 26/14 gear pass are given in the following table:



Specified Ratio	Number of 31/9 passes	Exact Ratio
6.3:1	1	6.3968
22:1	2	22.0335
76:1	3	75.8932
262:1	4	261.4099
900:1	5	900.4119
3,101:1	6	3101.4188
10,683:1	7	10682.6648
36,796:1	8	36795.8455
126,741:1	9	126741.2457

*results rounded to four decimal places

Non-integer gear ratios have been used in the design of FAULHABER gearheads other than those mentioned above as well. Exact gear ratios for commonly specified ratios from gearhead series 22/2 (spur type) and 16/7, 23/1, 30/1, and 38/1 (planetary) are given in the following tables:

Series 22/2		Series 16/7, 23/1, 30/1, 38/1, 38/2	
Specified Ratio	Exact Ratio	Specified Ratio	Exact Ratio
3.1:1	3.0625	14:1	13.7959
5.4:1	5.4444	43:1	42.9206
9.7:1	9.6979	66:1	66.2204
17.2:1	17.2407	134:1	133.5309
30.7:1	30.7101	159:1	159.4195
54.6:1	54.5957	246:1	245.9615
97.3:1	97.2486	415:1	415.4294
173:1	172.8863	592:1	592.1296
308:1	307.9538	989:1	988.8914
548:1	547.4733	1,526:1	1,525.7182
975:1	975.1869		
1,734:1	1,733.6656		
3,088:1	3,088.0918		
5,490:1	5,489.9410		
9,780:1	9,778.9573		

The use of non-integer gear ratios provides a clear advantage in terms of reduced gear noise and enhanced service life. If exact gear ratios rounded to a sufficiently accurate number of decimal places are used in the design of positioning servos, the problem of reconciling shaft position with encoder counts is eliminated.

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Direction of Rotation

The data sheets for smaller size, FAULHABER spur-type gearheads include a column which specifies “rotation direction”. The symbols used in the column are “=”, which stands for CW (clockwise rotation), and “≠”, which represents CCW (counterclockwise rotation). These symbols specify what direction the output shaft of the gearhead will rotate assuming that the motor shaft is rotating in a clockwise direction. The direction of rotation designation varies as a function of the total number of gear passes in the motor/gearhead system. An even number of gear passes results in no change in sense of direction from the motor to the gearhead output shaft. An odd number of passes results in a reversed rotation direction.

There are several important points to remember about specifying direction of rotation:

- **All FAULHABER gearheads can be driven in either clockwise or counterclockwise directions with equal performance.** The direction of rotation specification indicates only whether or not the sense of direction of the motor is reversed at the output shaft.
 - Gearheads using all planetary gear systems always maintain the sense of direction of the motor.
 - The convention used in the MicroMo catalog specifies direction of rotation as viewed from the output shaft end of the gearhead or the pinion end of the motor.
 - The fact that some gear ratios reverse the sense of motor rotation direction is not a limiting factor in using them. The motor direction of rotation can be changed by reversing the lead wires during installation. In addition, MicroMo can supply motors which rotate either clockwise or counter-clockwise with positive voltage applied to the '+' terminal or lead

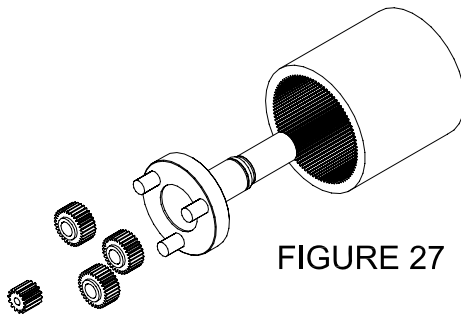


FIGURE 27

wire.

Planetary Gears

Planetary gearheads are typically used in applications where relatively high torque is involved. By distributing the forces over several gears per stage rather than just one gear/pinion pair as used in spur gears, the gearhead is capable of carrying higher torques without damage to gears or premature lubrication degradation.

Planetary gearheads are composed of satellite gears, a carrier plate with pins to fit the inside diameters of the satellite gears, an annular gear which usually forms the gearhead case on the outside and has gear teeth cut in the inside diameter, and a pinion from the driving motor. Figure 27 illustrates a single-stage planetary gearhead having three satellite gears. Attached to the carrier plate in Figure 27 is a shaft that protrudes through the bearings at the far end of the gearhead case for coupling to the load to be driven. In multi-stage gearheads, only the final stage has a shaft attached to the carrier plate. In the other stages, there is a gear (called a sun gear) attached to the carrier plate that serves to drive the next stage in the system. High gear ratios can be produced by lengthening the annular gear/case and stacking multiple stages.

For each stage of the planetary gearhead, the exact gear ratio can be determined using the following formula:

$$\text{ratio} = (R+S)/S \quad \text{where:}$$

S = number of teeth on pinion or sun gear

R = number of teeth on annular gear

For multiple stage gearheads, the total gear ratio is the product of the ratios of the individual stages. In the section on spur gear type gearheads, it was shown that the use of non-integer gear ratios is sometimes used as a means of reducing gear wear and audible noise. This is also the case with planetary gearheads. For example, MicroMo planetary gearhead series 14/1, 16/7, 23/1, 30/1, and 38/1 all use an annular gear with 57 teeth. Each stage uses a sun gear or pinion with either 21 teeth, 27 teeth, or 15 teeth. At the input end of the gearhead, the motor pinion always has 21 teeth. If one calculated the exact gear ratios for each listed gear ratio on catalog sheets, the results would look something

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like the following:

Number of Stages	Composition	Exact Ratio
1	$(57+21)/21$	3.7142857:1
2	$[(57+21)/21]^2$	13.795918:1
3	$[(57+21)/21]^2 \times (57+27)/27$	42.920635:1
3	$[(57+21)/21]^2 \times (57+15)/15$	66.220408:1
4	$[(57+21)/21]^2 \times [(57+27)/27]^2$	133.530864:1
4	$[(57+21)/21]^3 \times (57+27)/27$	159.419501:1
4	$[(57+21)/21]^3 \times (57+15)/15$	245.961516:1
5	$[(57+21)/21]^2 \times [(57+27)/27]^3$	415.429356:1
5	$[(57+21)/21]^4 \times (57+27)/27$	592.129576:1
5	$[(57+21)/21]^2 \times [(57+15)/15]^2 \times [(57+27)/27]$	988.891429:1
5	$[(57+21)/21]^2 \times [(57+15)/15]^3$	1,525.718203:1

When using planetary gearheads, the direction of rotation at the gearhead output is always the same as the direction of the motor rotation at the input.

Planetary gearheads are typically specified in applications where space is limited and the use of a similarly sized spur-type gearhead would result in unacceptably short service life. The use of planetary gearheads also has its disadvantages, however. Planetary gearheads are typically noisier than spur-type gearheads under similar operating conditions. They are usually less efficient than spur-type gearheads given similar ratios, and they are more expensive than comparable spur-type gearheads. But if the application requires relatively high torques, and size is a consideration, planetary gearheads are often the appropriate choice.

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