AGMA'S NEW RECOMMENDATIONS FOR SIZING OILFIELD PUMPING UNIT GEAR REDUCERS

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ABSTRACT

The American Gear Manufacturers' Association introduced its first recommendation for sizing oilfield pumping unit gear reducers in the year 1935. This recommendation eventually became AGMA Standard 422.02 and was incorporated in API Standard 11E. Since 1935 the only major change in API Standard 11E has been the addition of ductile iron as a gear material.

AGMA's new standard, AGMA 422.XX, covers recommended gear ratings based on tooth strength as well as pitting resistance. The present standards, AGMA 422.02 and API 11E, do not include specific recommendations for tooth strength. AGMA 422.XX also includes recommendations for sizing surface hardened gears in addition to thru hardened gears covered in the present standards.

A detailed comparison between the new and old ratings, as well as the physical size of some typical oilfield pumping unit reducers, is illustrated and discussed.

INTRODUCTION

In the past few years the American Gear Manufacturing Association (AGMA) has been engaged in a positive program of updating their design standards to reflect the current state of the art. The new standards address new concepts in gear technology and methods of manufacturing.

Such is the case with the proposed AGMA Standard 422.XX, "Standard Practice for Helical and Herringbone Speed Reducers for Oilfield Pumping Units". This new proposed standard has now successfully passed all the checks and balances required by the AGMA and as this paper goes to press (February, 1984) only needs the AGMA's board approval before final printing.

This new proposed standard will in all probability have a far reaching effect on the oil industry since the American Petroleum Institute (API) normally accepts AGMA's recommendations in formulating modifications to their own standard API Standard 11E.

AGMA's recommendations have been considered by an API task group and these recommendations have been submitted in the form of a letter ballot to members of API for their consideration. First results from this ballot probably will be available in the spring of 1984.

This paper will compare gear sizing methods recommended by the AGMA to the current API method which has been in effect (with modifications from time to time) since 1935.

SCOPE

AGMA's new recommendations include expanding the present range of through hardened gears up to 400 brinell hardness for gears and 440 BHN for pinions. The recommendations also include design criteria for surface hardened gears up to 58 Rockwell, "C" scale, (R_c).

There is at present very limited field data available on surface hardened gearing in the 58 R_c range for gear reducers operating in the oilfield although surface hardened gearing is widely used in Europe for most industrial applications.

It is not the purpose of this paper to evaluate or argue the validity of the gear sizing formulas (Figs. 1 and 2) recommended by the AGMA, but rather present them objectively to designers and users of oilfield pumping units for their own evaluation.

AGMA's recommendations include design formulas for pitting resistance (wear), operating bending strength, and static bending strength. Of these three design considerations the current API Standard 11E addresses only pitting resistance.

LIMITATIONS AND RESPONSIBILITY

AGMA recommends that designers and users applying the standard should be engineers with significant experience in mechanical systems. Further, they recommend that a pumping system analysis be the responsibility of the user. Loads on a pumping unit structure and gear reducer can be approximated by referring to API Recommended Practice API-RP-11L.

PARAMETERS

Variables included in AGMA's recommended design formulas include:

(1) Diameters of the gears and pinions.
(2) Face width of the gear set.
(3) Operating speeds.
(4) Gear materials (includes steel, ductile iron, malleable iron, and cast iron).
(5) Gear and pinion hardness.
(6) Gear tooth size.
(7) Helix angle of the gear set.
(8) Pressure angle of the gear set.

WEAR AND STRENGTH FORMULAS

Figs. 1 and 2 show the complexity of the durability and strength rating formulas proposed and how some of the variables mentioned above are used. It is apparent that the pitting resistance (wear) formula shown in Fig. 1 is much more complex than the comparable current pitting resistance formula in API STD 11E which has been in use since the mid-1930's:

$$T_{ac} = \frac{63{,}000 \times F_i \times K_r \times D_s}{n_o} \quad \text{(Current API STD 11E formula for wear)}$$

No attempt is made in this paper to present the current API gear rating formula or the proposed AGMA formulas in Figs. 1 and 2 in enough detail so that calculations can be made. Rather, the equations are only presented to show their relative complexity.

Perhaps of interest only to historians is a rating formula originally used by the first manufacturer of the conventional oilfield pumping unit. It limited the pressure on the gear teeth to 100 pounds per inch of face width per inch of pitch diameter of the pinion. Gear tooth physical size and hardness were not at that time considered a factor nor was any distinction made between pitting resistance and tooth strength. This very early rating method was used for many years before there was an API standard.

Mention was made earlier of the inclusion of operating bending and static bending strength formulas in AGMA's recommendations. These were not previously considered by API sizing methods.

The static rating is recommended by AGMA to be at least equal to 500% of the reducer name plate rating, the name plate rating being the lesser of either the pitting resistance rating, the bending strength rating or one of the standard torque ratings listed in the present STD 11E, i.e., 114, 160, 228, etc.

Static loads on gear teeth can be caused by resisting the torque exerted by the counterbalance, pumping unit brakes, and other non-operating conditions. Torque levels caused by static loads will very often be many times the normal operating torque of the gear reducer. The many conditions of installation, maintenance, and use of pumping unit reducers which can cover high static torques to be applied is not within the scope of this paper.

NEW AGMA AND CURRENT API SIZING COMPARISONS

In an effort to objectively evaluate AGMA's new sizing recommendations, three API double reduction gear reducer sizes - 114, 320, and 912 - were selected for evaluation. To each of these three reducers, gear sets were arbitrarily chosen to effect a torque rating just slightly over the name plate rating for the reducer as required by the new AGMA sizing method. Pitch diameters, center distances, face widths, etc. were arbitrarily chosen, but it is felt that the values chosen are typical of good gear design. Further, three different hardness ranges - 255 BHN, 300 BHN, and 58 R_c - were applied to each of the gear reducers. These arbitrarily chosen gear sets are tabulated in Tables 1, 2, and 3.

For the gear sets in Tables 1, 2, and 3, the pitting resistance (wear) rating, operating bending strength ratings (for both gear and pinion), and static bending strength ratings (for gear and pinion) were all calculated for steel gears and for steel pinions using AGMA's new recommendations. The pitting resistance rating of these same gear sets were then compared to the pitting resistance rating using the current API method up to and including 300 brinell gears which is the present top limit in API STD 11E. As was mentioned earlier, no strength comparisons could be made since the current API standard has no specific strength recommendations.

Calculated torque values for the gear sets are tabulated in Table 4. It can be seen from Table 4 that the new AGMA recommendations allow an increase in the pitting resistance rating of approximately 4 - 6%.

In order to get a feel for the effect of gear tooth hardness on the physical size of gear reducers sized by the new AGMA method, Fig. 3 was prepared. Fig. 3 shows the approximate physical size of the gear reducers equipped with gear sets tabulated in Tables 1, 2, and 3 for the three different hardness ranges chosen.

DUCTILE IRON AS A GEAR MATERIAL

Referring to the last multiplier in Fig. 1, $(s_{ac}/C_p)^2$, note that for any given allowable stress, s_{ac} , the rated torque, T_{ac} , based on pitting resistance is a direct function of $(1/C_p)^2$ if all other variables remain constant. AGMA allows the use of an allowable stress in ductile iron gears equal to that of steel if adequate metallurgical controls are maintained.

For ductile iron gears operating with steel pinions the C_p value is 2160, whereas for a steel pinion operating with a steel gear, the C_p value is 2300. Thus, it can be seen that the rated torque, T_{ac}, is increased by a factor of $[(2300/2160)^2 - 1]$ or an increase of 13.4% when a steel pinion is run with a ductile iron gear. This 13.4% increase is over and above the approximate 4% - 6% increase referred to earlier. The 13.4% increase is an increase in pitting resistance only. It does not apply to tooth strength.

COMPONENT DESIGN

Although no detailed discussion is presented here, it should be mentioned that the new recommendations of the AGMA 422.XX standard recommend some general and some specific design parameters for other components of the gear reducer other than the gear sets themselves. Other components covered are as follows:

Reducer Housings,
Sleeve and Anti-friction Bearings,
Allowable Shaft Stresses,
Allowable Shaft Deflections,
Allowable Key Stresses,
Threaded Fasteners,
Seals and Breathers,
Lubrication.

CONCLUSIONS:

Since this paper is intended primarily as a presentation of the recommendations of AGMA to users and designers, no specific conclusions are drawn. The integrity of the new AGMA recommendations, if adopted by the API and incorporated in their Standard 11E, would have to stand the test of time just as have other new standards adopted in the past.

Rated Torque; Pinion RPM; Pinion Pitch Diameter; Pitchline Velocity; Face Width; Pressure Angle; Gear Ratio; Length of Lines of Action; Allowable Stress; Output Shaft RPM; Face Width; Elastic Coefficient

$$T_{ac} = \frac{n_p d^2 \dfrac{78}{78 + \sqrt{v_t}}}{2n_o} \cdot \frac{F}{(1.24 + .0312F)} \cdot \frac{\cos\phi_t \ \sin\phi_t}{2} \cdot \frac{m_G}{m_G + 1} \cdot \frac{L_{(min.)}}{F} \cdot \left(\frac{s_{ac}}{C_p}\right)^2$$

Figure 1 - AGMA proposed torque rating equation based on pitting resistance (wear)

Rated Torque; Pinion RPM; Pinion Pitch Diameter; Pitchline Velocity; Face Width; Allowable Stress; Geometry Factor (from layout); Output Shaft RPM; Diametral Pitch

$$T_{at} = \frac{n_p d \sqrt{\dfrac{78}{78 + \sqrt{v_t}}}}{2n_o} \cdot \frac{F}{\left(\dfrac{1}{.872 - .0176F}\right)} \cdot s_{at} \cdot \frac{J}{P_d}$$

Figure 2 - AGMA proposed torque rating equation based on tooth strength

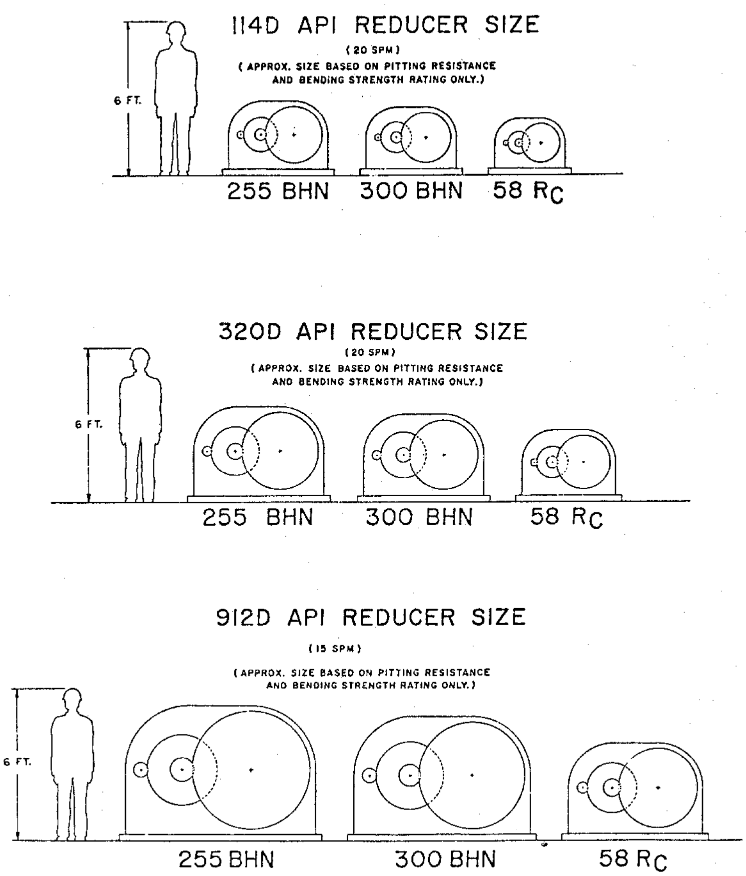

Figure 3

Table 1
Assumed Gear Sets for API 114 Gear Reducer
(Steel Gears and Pinions)

HIGH SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	21	19	12
NO. TEETH, Gear	112	101	63
RATIO	5.333	5.316	5.250
PITCH DIAMETER, Pinion (Inches)	3.000	2.714	2.000
PITCH DIAMETER, Gear (Inches)	16.000	14.429	10.500
CENTER DISTANCE (Inches)	9.500	8.571	6.250
EFFECTIVE FACE (Inches)	3.11	2.86	2.11
DIAMETRAL PITCH (Transverse)	7	7	6
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

LOW SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	19	17	11
NO. TEETH, Gear	105	94	62
RATIO	5.526	5.529	5.636
PITCH DIAMETER, Pinion (Inches)	4.750	4.250	3.143
PITCH DIAMETER, Gear (Inches)	26.250	23.500	17.714
CENTER DISTANCE (Inches)	15.500	13.875	10.429
EFFECTIVE FACE (Inches)	6.11	5.86	4.36
DIAMETRAL PITCH (Transverse)	4	4	3.5
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

Table 2
Assumed Gear Sets for API 320 Gear Reducer
(Steel Gears and Pinions)

HIGH SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	20	19	11
NO. TEETH, Gear	113	107	58
RATIO	5.650	5.632	5.723
PITCH DIAMETER, Pinion (Inches)	4.000	3.800	2.750
PITCH DIAMETER, Gear (Inches)	22.600	21.400	14.500
CENTER DISTANCE (Inches)	13.300	12.600	8.625
EFFECTIVE FACE (Inches)	4.86	4.11	3.36
DIAMETRAL PITCH (Transverse)	5	5	4
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

LOW SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	20	18	11
NO. TEETH, Gear	107	96	62
RATIO	5.350	5.333	5.636
PITCH DIAMETER, Pinion (Inches)	6.667	6.000	4.400
PITCH DIAMETER, Gear (Inches)	35.667	32.000	24.800
CENTER DISTANCE (Inches)	21.167	19.000	14.600
EFFECTIVE FACE (Inches)	9.86	9.36	6.36
DIAMETRAL PITCH (Transverse)	3	3	2.5
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

Table 3
Assumed Gear Sets for API 912 Gear Reducer
(Steel Gears and Pinions)

HIGH SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	22	21	11
NO. TEETH, Gear	115	110	58
RATIO	5.227	5.238	5.273
PITCH DIAMETER, Pinion (Inches)	6.286	6.000	4.400
PITCH DIAMETER, Gear (Inches)	32.857	31.429	23.200
CENTER DISTANCE (Inches)	19.571	18.714	13.800
EFFECTIVE FACE (Inches)	6.36	5.11	3.86
DIAMETRAL PITCH (Transverse)	3.5	3.5	2.5
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

LOW SPEED SET	255 BHN GEARS	300 BHN GEARS	58 Rc GEARS
NO. TEETH, Pinion	20	18	10
NO. TEETH, Gear	110	99	55
RATIO	5.500	5.500	5.500
PITCH DIAMETER, Pinion (Inches)	10.000	9.000	6.667
PITCH DIAMETER, Gear (Inches)	55.000	49.500	36.667
CENTER DISTANCE (Inches)	32.500	29.250	21.667
EFFECTIVE FACE (Inches)	13.11	12.36	8.86
DIAMETRAL PITCH (Transverse)	2	2	1.5
HARDNESS, Pinion	300 BHN	350 BHN	58 Rc
HARDNESS, Gear	255 BHN	300 BHN	58 Rc

Table 4
Torque Calculations (Pound Inches)
(Assumed Gear Sets in Tables 1, 2, and 3)

		Per API-11E		Per AGMA 422.XX		
		Durability	Strength	Durability	(*)	Strength (Gear/Pinion)
API 114 REDUCER (20 S.P.M.)	255 BHN	HS 113,418	No Strength Rating	HS 120,769	(+6.5%)	HS 155,674 G 194,291 P
		LS 110,914	"	LS 115,659	(+4.3%)	LS 153,933 G 192,877 P
	300 BHN	HS 112,738	"	HS 118,423	(+5.0%)	HS 142,591 G 175,812 P
		LS 112,597	"	LS 115,616	(+2.7%)	LS 145,395 G 179,971 P
	58 Rc	HS N/A	"	HS 117,580		HS 129,496 G 150,766 P
		LS N/A	"	LS 119,491		LS 134,697 G 157,076 P
API 320 REDUCER (20 S.P.M.)	255 BHN	HS 305,089	"	HS 321,052	(+5.2%)	HS 437,856 G 546,158 P
		LS 305,457	"	LS 321,224	(+5.2%)	LS 409,908 G 513,039 P
	300 BHN	HS 306,731	"	HS 321,169	(+4.7%)	HS 393,008 G 482,961 P
		LS 311,283	"	LS 321,991	(+3.4%)	LS 387,226 G 478,769 P
	58 Rc	HS N/A	"	HS 333,973		HS 400,290 G 470,246 P
		LS N/A	"	LS 320,361		LS 364,413 G 424,958 P
API 912 REDUCER (15 S.P.M.)	255 BHN	HS 879,306	"	HS 934,210	(+6.2%)	HS 1,189,127 G 1,481,535 P
		LS 866,674	"	LS 921,016	(+6.3%)	LS 1,153,167 G 1,440,865 P
	300 BHN	HS 864,608	"	HS 913,250	(+5.6%)	HS 1,040,577 G 1,276,592 P
		LS 883,124	"	LS 924,343	(+4.7%)	LS 1,094,017 G 1,350,393 P
	58 Rc	HS N/A	"	HS 931,413		HS 1,126,663 G 1,323,559 P
		LS N/A	"	LS 936,775		LS 1,140,718 G 1,348,908 P

*Values in parenthesis show increase in durability rating over current API 11E method at left.