API Pumping Units

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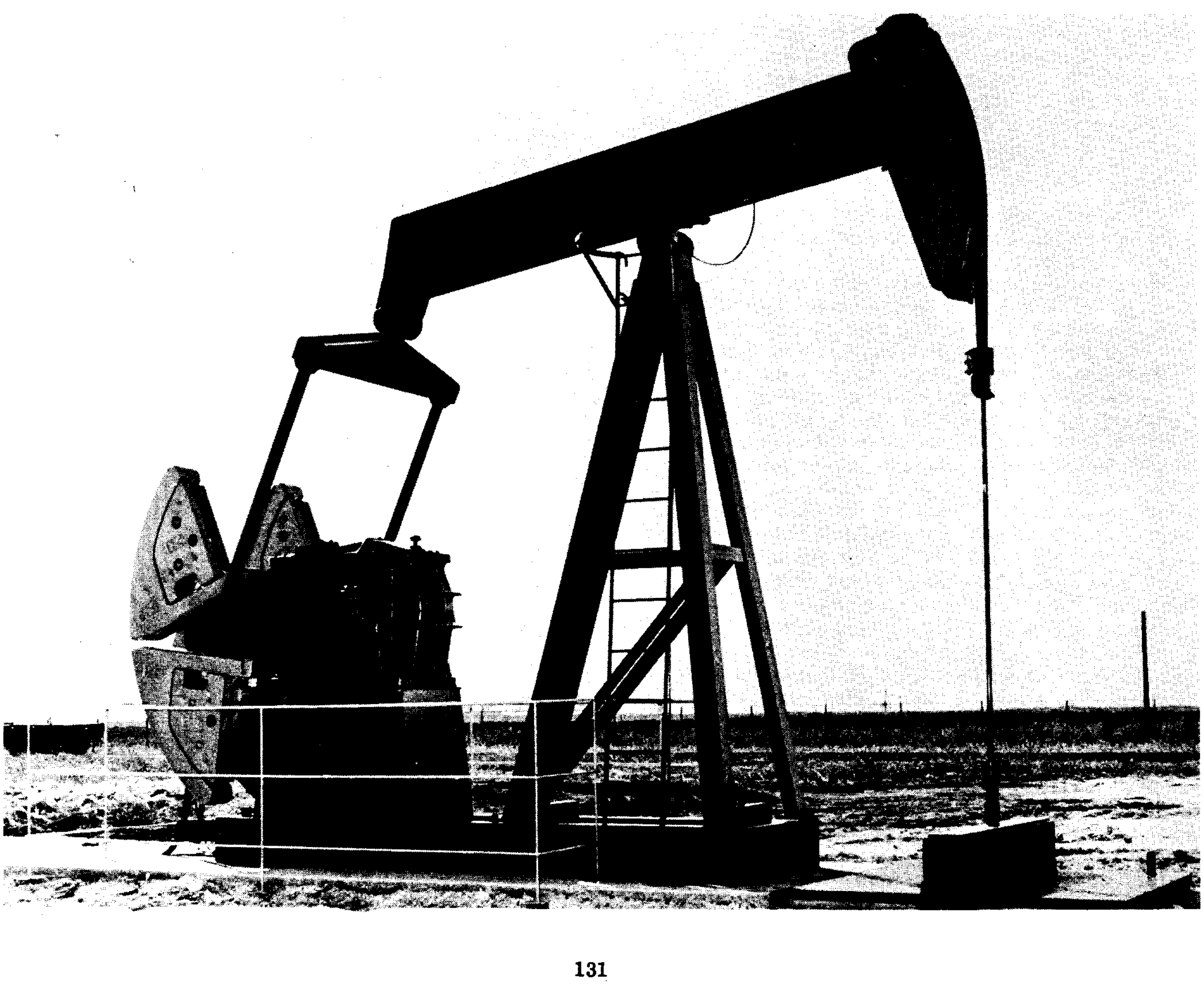
What is an API pumping unit? What design characteristics are controlled by API Standards? What benefit does the user gain in API units as compared with the tailor-made variety? These are a few of the questions many operators are asking and which may be considered to be the basic subject of this paper.

Oil field pumping units as we know them today do not look very much different from the oil lifting rigs which were used 25 or even 50 yrs ago. They still operate on the same basic principle -- a walking beam pivoted at the center with one end attached to a string of sucker rods which actuate a positive displacement plunger pump at the bottom of the well to lift oil through the tubing. Power is transmitted to the walking beam from an engine or electric motor through a reduction gear which reduces prime mover speed down to the 10 to 20 SPM level required by the rod string. The rotary motion of the gear is converted to reciprocating motion to actuate the walking beam by means of a crank and pitman mechanism. Counterweights on the tail end of the walking beam, or a rotary counterweight on the cranks is provided to balance the dead weight of the rod string and part of the fluid weight to minimize the torque load on the reduction gear and prime mover.

All these details are familiar oil field sights and have been with us so long that one wonders why such an apparently crude mechanism has not been replaced long before this by more refined equipment. We know, of course, that, for lifting oil there are in use other methods such as the hydraulic subsurface pump, the gas lift and the electric submersible pump, and many others. However, for pumping oil wells ranging from the shallowest to 7,000 or 8,000 ft depth and for normal production rates, beam type pumping equipment is hard to beat for economy, minimum attention and upkeep, and long, trouble free performance. Other types of rod lifting type mechanisms have also been on the market; some have become quite popular in localized areas. The hydraulic pumping unit, with or without pneumatic counterbalance, is a good example and received good acceptance in the metropolitan areas of California, but its popularity now appears to be waning and most new installations are now beam type pumping units or hydraulic subsurface pumps, except where city ordinances preclude their use.



Since API has considered only beam type pumping units in its standardization program, this discussion will be limited to this class of equipment.

While at first glance beam pumping units today may look very much like units of 25 or 30 yr ago, actually many improvements have been made to make today's unit a much more efficient and dependable machine. A few of these developments are:

(1) Rotary Counterbalance: beam counterbalance on large pumping units resulting in high inertia forces developed on each stroke reversal and beam failures were common. Beam counterbalance is now used only on the smaller pumping units where the inertia effect is negligible.
(2) Roll back arc heads: facilitating well servicing.
(3) Complete unitization: minimizing installation expense.
(4) Improved gearing: because of better machine tooling and anti-friction bearings.
(5) Adjustable rotary counterweight: providing easier and safer adjustment.
(6) Improved geometry: reducing inertia forces on the rod string.
(7) Improved materials and manufacturing methods.
(8) Prime movers of greater efficiency.
(9) Automated controls.

The lack of equipment standardization in past years created many problems for the operators. Each machinery manufacturer was an individualist who considered his own designs and choice of dimensions best. So oil field machinery came to be made in a multitude of sizes and shapes. Many years ago the users group in the American Petroleum Institute recognized this situation and started the API standardization program and attempted to bring order out of the chaos which then existed in the industry.

The objective of standardization is to reduce costs, and both the operators and manufacturers should benefit from any standardization program for the following reasons:

(1) Minimizes field stock requirements for user.
(2) Minimizes field stock requirements for the manufacturer.
(3) Makes parts more generally available from suppliers' stocks, and reduces down time for the user.
(4) Reduces manufacturing costs by increasing job lot quantities; higher production tooling justified.
(5) Standards on ratings assure user of uniform equipment capacity from any manufacturer.

For production equipment, initial standardization efforts were directed at the material -- such as tubing, casing, sucker rods and subsurface pumps -- in the well. All this material is now well standardized, and the users owe a vote of thanks to the API for its accomplishment. The latest of these standards on well equipment is 11-AX which establishes standard subsurface pump assemblies of various types. Standards such as these save the producing industry money every day.

Surface machinery has been relatively more resistant to efforts at standardization. In 1943, API appointed a committee to study pumping unit standardization and a proposal was made in 1945. This proposal included standards for gear size, peak torque, structure size, maximum stroke, polish rod rating, beam working centers, and samson post height. Unfortunately this proposal attempted to standardize too many details of unit design and was voted out. The inclusion of dimensions affecting geometry undoubtedly caused the rejection of this proposal.

Fortunately all of this committee's labor was not in vain because API subsequently adopted part of its recommendations--those pertaining to pumping unit reduction gears. API adopted a series of gear box sizes based on peak torque ratings as shown in Table I.

Table I

Pumping Unit Reducer Sizes and Ratings

Size	Peak Torque Rating (in. lb)
6.4	6,400
10	10,000
16	16,000
25	25,000
40	40,000
57	57,000
80	80,000
114	114,000
160	160,000
228	228,000
320	320,000
456	456,000
640	640,000
912	912,000
1280	1,280,000
1824	1,824,000

In Table I, it will be noticed that, for sizes 6.4 to 40, each size is determined by multiplying $\sqrt{2.5}$ or 1.58 times the next smaller, or each size is 2.5 times the second size smaller. Sizes above API 40 are determined by multiplying $\sqrt{2}$ or 1.414 times the next smaller size, or each size is two times the second size smaller.

The peak torque rating method had been standardized earlier by API based on AGMA (American Gear Manufacturers Association) standards with some slight modification to suit operating conditions peculiar to pumping units. Previously, gear ratings were determined by each manufacturer according to his best judgment.

The present API Standard 11E assures the user that for any given combination of gear hardness, ratio, speed, face width and pitch diameter, the gear rating will be the same, regardless of manufacturer.

The gear rating portion of the standard establishes the peak torque rating based on only surface durability. The AGMA rating for strength is not included in the API standard and it is the manufacturer's responsibility to select a tooth pitch of adequate strength to match the durability rating. The gear peak torque rating may be determined from the formula

$$\text{Torque (in. lb)} = \frac{Fi\ Kr\ N\ Dp^2}{40 + .513\sqrt{V}}$$

Where Fi = Face width factor (From curve Fig. 1)
Kr = Factor for materials, toothform and ratio (From Curve Fig. 2)
N = Pinion RPM
Dp = Pinion pitch diameter, in.
V = Pitch line velocity - ft per minute (Based on 20 SPM)

The torque formula above is presented in somewhat different form from the formula shown in API Standard 11E, but it is simply an algebraic rearrangement consolidating all variables in one formula, and it will produce the same result.

The manufacturer, after determining his gear rating by formula, must rate the reduction gear at the next smaller standard peak torque rating shown in Table I and must not refer to the actual calculated rating in sales literature or specifications.

At this point detailed explanation of API gear rating methods is necessary to outline the similarities and variances in comparison with the AGMA gear ratings and to develop a better understanding of the pumping unit gear and its application. It is a common misconception that excess capacity is built into pumping unit gears, and this fallacy will be recognized with an understanding of the API and AGMA rating methods.

Figure 1 is a curve from which the Fi factor in the rating formula may be determined, if the gear face width is known. It will be seen that Fi for both API and AGMA ratings are identical up to 12 in. face width which would be roughly equivalent to API 456 gears of average hardness. For larger gears, Fi for API rating is higher than for AGMA, and the API torque rating would be proportionately higher than AGMA. This difference is a maximum for 18 in. face width when it amounts to 11 per cent. However, for the AGMA rating the Fi curve in Fig. 1 applies only to the high speed gears while in the API rating it applies to both low speed and high speed gears. The AGMA uses another curve for rating the low speed gears which provides a higher Fi value and consequently a higher torque rating than does the API rating. The Fi values from this AGMA curve for low speed gears are 30 per cent to 35 per cent greater than are those determined from the curve for the high speed gears and for the same face width. AGMA low speed gear torque ratings would thus be higher than API low speed gear ratings by this amount; and this difference gives the API gear rating for low speed gears a built-in application factor of 1.30 to 1.35 as compared with the AGMA rating.

At first glance this factor would seem to be a decided advantage for the API gear rating, except that AGMA further modifies the torque rating by an application factor for the class of service, degree of shock loading, duration of operating periods, etc.. For 24 hr per day service, moderate shock, with single cylinder internal combustion engine drive, AGMA specifies an application factor of 2.0. The operating torque must be multiplied by this application factor and the gears selected with an AGMA torque rating to match this value. Thus it is apparent that a gear selected by AGMA methods for 24 hr service with single cylinder engine would actually be 2.0/1.35 or 1.48 times as capable as would that determined by the API standard. However, for electric motor drive, the AGMA application factor is only 1.5. Therefore, for this application a gear selected by AGMA method would be 1.5/1.35 or 1.11 times as large as by API methods.

Another important factor entering into the gear torque rating is the Kr factor which varies with gear ratio and is determined from the curves in Figure 2. These curves are identical to their AGMA counterpart. In this family of curves it will be noted that each curve is for a gear and pinion of specified minimum Brinell hardness. The pinion is always made somewhat harder than is the gear since in proportion to the gear ratio each tooth of the pinion must make more contacts than does a tooth in the gear. In other words, for a 5:1 gear ratio each pinion tooth would make five times as many contacts as does a gear tooth. The hardness combinations shown on each curve represent the combinations which have been found to result in balanced wear between gear and pinion.

To suit his manufacturing facilities or the space limitations in the gear cases the manufacturer is at liberty to select any of the hardness combinations shown in Figure 2. Most manufacturers today make their gears to the medium hardness range; but several are making gears to the maximum hardness and a number of manufacturers make gears of different capacities to different hardness curves. In general, the higher hardness combinations will result in gears of smaller size. Aircraft gears are a good example of this principle carried to the extreme where carburized, case hardened and ground gears must be used for minimum weight and extreme compactness. Usually, however, the cost of such gears is excessive for industrial applications and for this reason case-hardened gears are not covered by the API

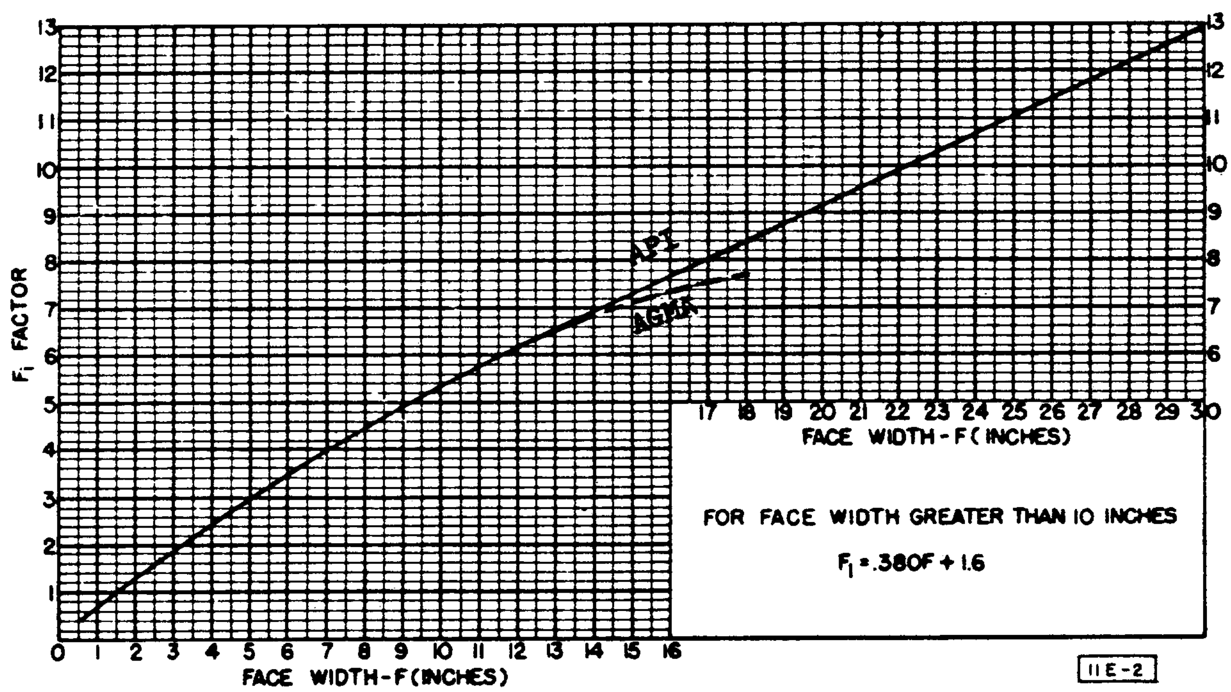


FIGURE 1 - Fi FACTOR VS. GEAR FACE WIDTH
(From API Std. 11E)

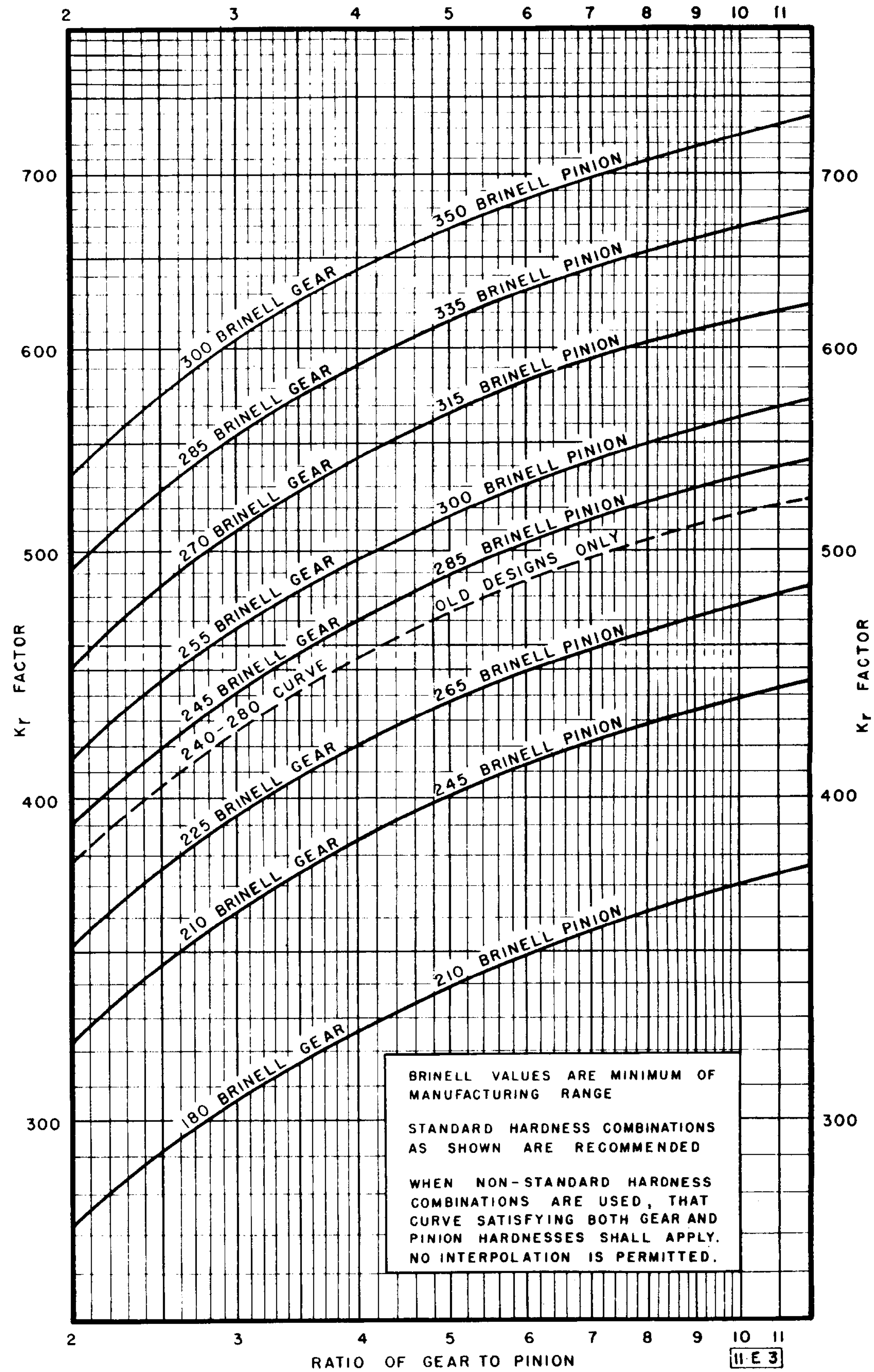


FIGURE 2 VARIATION OF K_r FACTOR WITH GEAR RATIO.

FROM API STD. 11E

VARIATION OF F_i FACTOR WITH FACE WIDTH — AGMA STD. 211.01

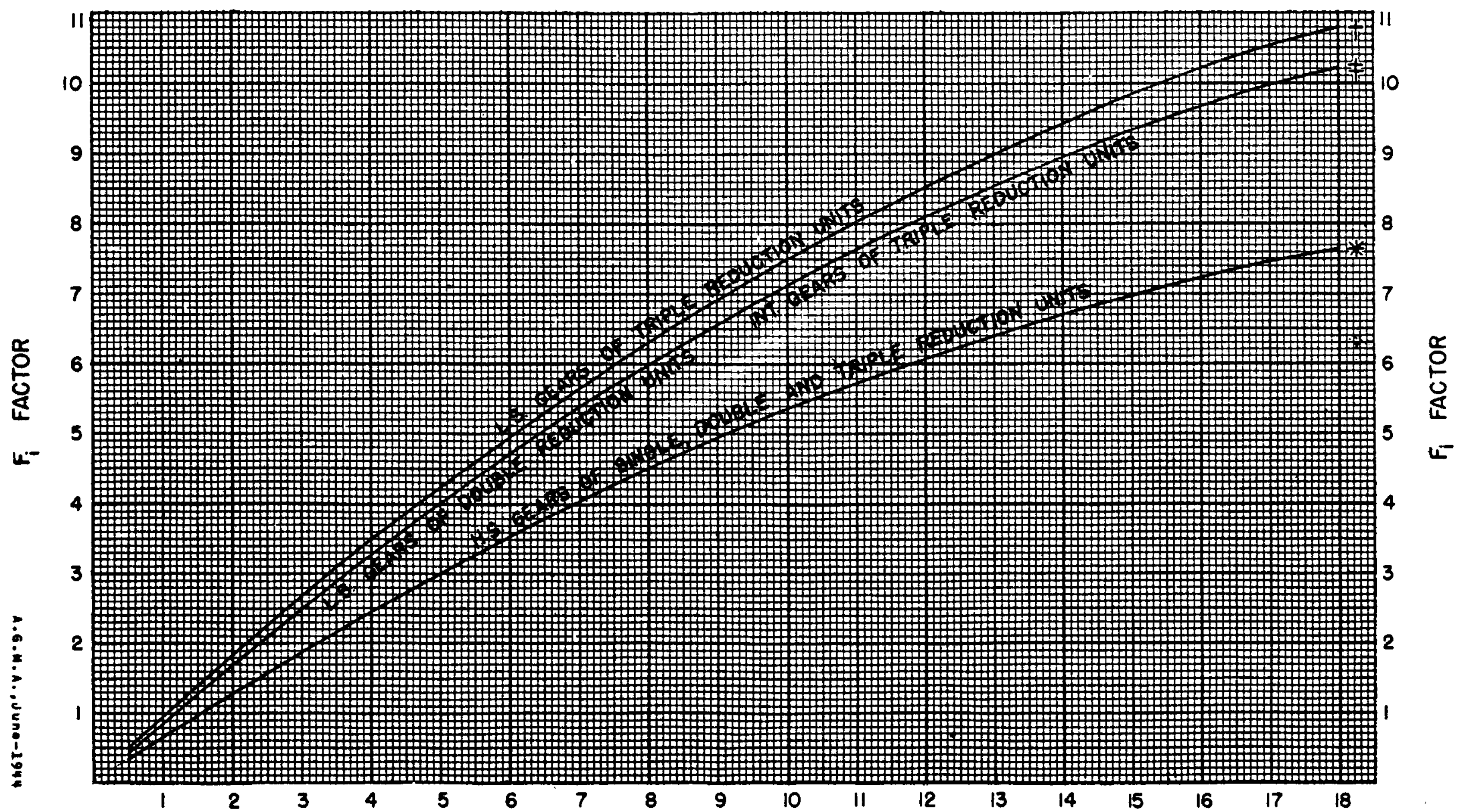


FIGURE 3

FOR FACE WIDTH GREATER THAN 18"

† F_i = .600 F 0.600 F

‡ F_i = .570 F 0.570 F

✱ F_i = .425 F 0.425 F

A.G.M.A., June-1944

standard. One manufacturer does use case hardened gears in one small unit size, but it is a non-API unit.

In sizing pumping unit gears to actual well requirements the peak torque is calculated from the well load, impulse factor, and optimum counterbalance; and the reduction gear is selected with an API peak torque capacity to match. Other than the built-in factor no other application factors are used. As pointed out previously, the built-in factor was obtained by using the AGMA high speed gear Fi curve for both low and high speed gear API ratings, which results in the AGMA rating for low speed gears being about 35 per cent higher than is the API rating for the same gears; while high speed gear ratings are the same for API and AGMA. The net result is that in terms of AGMA rating, the API rating causes low speed gears to be applied against actual torque requirements with an application factor of 1.35 as compared with AGMA's recommended 2.0 for 24 hr service with single cylinder engine drive.

High speed gears are applied with a factor of only 1.0 against peak torque requirements. But this application is not as serious as it might seem since the peak torque is generally considered to be about 1.57 times the average torque, so 1.57 could be taken as the value of the application factor. Unfortunately, however, low speed gear torque does not average out because the peak torque must always be carried by the same few gear tooth on the low speed gear, while other teeth may carry relatively light loads. Therefore, the low speed gear will very likely show an erratic wear pattern around its periphery.

When all aspects are considered, pumping unit gears applied according to manufacturers' recommendations and API ratings will result in gear loading equivalent to that recommended by AGMA for moderate shock service with:

(1) Electric motor drive up to 24 hr per day.
(2) Multi cylinder internal combustion engine drive up to 10 hr per day.
(3) Single cylinder internal combustion engine drive up to three hr per day.

If a pumping unit gear were applied strictly in accordance with AGMA standards for 24 hr per day service with single cylinder, internal combustion engine drive, the gear should be selected with a torque rating 2.0/1.35 or 1.48 times the calculated peak torque. In other words, it should be sized 50 per cent larger than is presently recommended. This calculation points up a possible weakness in the present API rating standard a weakness which possibly should receive attention.

Table 2 shows AGMA service factors for moderate shock loading typical of pumping unit gears.

Chain reducers receive very little attention in the API standards, probably because they represent a relatively small part of total pumping unit production. API does specify the following:

(1) Chain shall be American Standard B29.1 heavy series with press fitted center link plates.
(2) Sprockets shall have American Standard toothform.
(3) Small sprocket shall have a minimum hardness of 225 Brinell. Large sprocket shall be steel or cast iron.
(4) A minimum chain take-up of 2 in. shall be provided.
(5) The peak torque rating shall be based on the American Standard ultimate breaking strength of the chain divided by 12, or

$$\text{Peak Torque, } T = \frac{SR}{12}$$

Where: S = American Standard ultimate chain strength.
R = Pitch radius of large sprocket, inches.

Table 2

SERVICE FACTORS

Prime Mover	Duration of Service	Driven Machine Load Classification Moderate Shock
Electric Motor	Occasional 1/2 hr per day	*0.80
	Intermittent 3 hr per day	1.00
	8 to 10 hr per day	1.25
	24 hr per day	1.50
Multi-Cylinder Internal Combustion Engine	Occasional 1/2 hr per day	1.00
	Intermittent 3 hr per day	1.25
	8 to 10 hr per day	1.50
	24 hr per day	1.75
Single-Cylinder Internal Combustion Engine	Occasional 1/2 hr per day	1.25
	Intermittent 3 hr per day	1.50
	8 to 10 hr per day	1.75
	24 hr per day	2.00

*Maximum momentary or starting load must not exceed 160 per cent of normal. (100% overload)

Pumping Unit Structure Ratings have been standardized very recently, and appeared for the first time in the Ninth Edition of API Standard 11E, January 1961. However, for many years, the API has had standards specifying the method and stress for calculating beam capacity.

The API beam rating standard authorizes the use of ASTM A-7 structural steel which is regular low carbon steel, and this material may be stressed to 10,000 psi maximum in tension. If the ratio of beam length to flange width exceeds 15, then the maximum compressive stress must be reduced below 10,000 psi as determined by the formula

$$f_{bc} = \left[\frac{11250}{1+\frac{\ell^2}{1800\,b^2}}\right]$$

Where f_{cb} = maximum compressive stress psi
ℓ = beam length (unbraced), inches.
b = flange width, inches.

Beam capacity may be calculated from

$$W = \frac{f_{cb}\,S}{a}$$

Where W = walking beam rating in pounds
f_{bc} = allowable compressive stress, psi
S = section modulus of beam, inches cubed.
a = distance from centerline saddle bearing to well, inches.

The standard also authorizes a second beam material of silicon structural steel ASTM A-94. This material may be stressed to 13,600 psi. However, because of its poor welding properties, silicon steel has dropped out of use. API is considering the addition of A-36 structural steel which would provide approximately ten per cent more load carrying capacity for the same beam size.

The rating of all other components of the structure must be based on stress limits consistent with those of the walking beam

The recent establishment of standard pumping unit sizes is potentially the most important development in API pumping unit standardization efforts. Its success will depend largely upon the cooperation of the users, many of whom have been accustomed to asking for and receiving units to their exact specifications. It should be obvious that special units made in small quantity lots must cost more than do standard units made in larger quantities. Thus, reduction in pumping unit cost depends largely on increased volume of production in each size.

Recognizing this fact, API renewed its efforts to establish a workable pumping unit structure standard. All major manufacturers were surveyed to determine the combinations of reducers, beam ratings and stroke lengths produced during 1956 and 1957. It was found that, in this period, over 350 different sizes had been in production. The new standard encompasses a series of 93 pumping unit sizes which will effectively satisfy nearly all application requirements. This series is presented in Table 3.

Table 3

API PUMPING UNIT SIZES (Gear Size-Beam-Stroke)

	6.4-32-16
	6.4-21-24
	6.4-32-24
FR1	10-32-16
	10-21-24
	10-32-24
	....
	10-40-20
	10-27-30
	10-40-30
FR2	16-40-20
	16-27-30
	16-40-30
	....
	16-53-24
	16-43-30
	16-53-30
FR3	25-53-24
	25-43-30
	25-53-30
	....
	25-67-30
	25-56-36
	25-67-36
FR4	40-67-30
	40-56-36
	40-67-36
	....
	40-89-36
	40-76-42
	40-89-42
FR5	57-89-36
	57-76-42
	57-89-42
	....
	57-109-42
	57-95-48
	57-109-48
FR6	80-109-42
	80-95-48
	80-109-48
	....
	80-133-48
	80-119-54
	80-133-54
FR7	114-133-48
	114-119-54
	114-133-54
	....
	114-169-54
	114-143-64
	114-169-64

FR8	160-169-54
	160-143-64
	160-169-64
	....
	160-200-64
	160-173-74
	160-200-74
FR9	228-200-64
	228-173-74
	228-200-74
	....
	228-246-74
	228-212-86
	228-246-86
FR10	320-246-74
	320-212-86
	320-246-86
	....
	320-298-86
	320-256-100
FR11	320-298-100
	320-213-120
	320-256-120
	456-298-86
	456-256-100
	456-298-100
	456-213-120
	456-256-120
	....
	456-365-100
	456-304-120
	456-365-120
	456-253-144
FR12	456-304-144
	640-365-100
	640-304-120
	640-365-120
	640-253-144
	640-304-144
	....
	640-427-120
	640-356-144
	640-427-144
	640-305-168
FR13	640-356-168
	912-427-120
	912-356-144
	912-427-144
	912-305-168
	912-356-168
	....
FR14	912-380-192
	912-427-192

Probably very few manufacturers will build the complete API series of sizes. This manufacturer, for example, will build sizes from the 16-40-20 to the 456-256-210, representing sixty-one basic sizes, and these will probably be typical of the majority of manufacturers. To load the beams to capacity the largest units on the API list will require special sucker rods not in regular production; and, where oil production is not prorated it will very likely be applied primarily in foreign fields.

It should also be born in mind that the manufacturer must produce many of the basic API units in different types. For example, gear sizes API 25 up to API 80 must be furnished on structures with high gear sub-bases for crank counterbalance, and also on structures with low gear sub-bases and longer beams for beam counterbalance.

An explanation of the method by which the API Standard Pumping Unit Series was established may be of more than academic interest and should dispel any thought that the unit ratings were selected arbitrarily.

First, from the survey of manufacturers unit production 1956 and 1957, it was possible to establish the most popular maximum stroke lengths associated with each reduction gear. The standard stroke lengths established are 16, 20, 24, 30, 36, 42, 48, 54, 64, 74, 84, 86, 100, 120, 144, 168 and 192 inches. Referring to Table 4, it will be seen that for structure series A, each of the stroke lengths up to 144 in. is matched to two gear sizes, the smaller gear being the basic size and the larger being the alternate or optional size.

Beam or structure rating was determined from the formula:

$$C = \frac{8 \times PT}{S}$$

Where C = beam or structure capacity, pounds
PT = reducer peak torque capacity, inch pounds
S = maximum stroke length, inches

The above formula is based on counterbalancing 75 per cent of the beam capacity. Substituting in the formula the peak torque rating for the basic gear and the maximum stroke length, produces the beam rating for the Series A units.

The Series B units are a longer stroke version of Series A. It was envisioned that they might be produced from Series A units in two ways: (1) by applying a longer crank which would produce the longer stroke with the same beam rating as Series A units; and (2) by extending the Series A beam to produce the longer stroke but at proportionately reduced beam capacity. Actually, API Standard 11E does not specify the mechanics by which Series B and C beam ratings and stroke lengths are obtained, nor was this intended.

The Series C units are a still longer stroke version of Series A but limited to API gears 320 and larger. The smaller of the two beam ratings in each pair is the rating which would result if the smaller Series B beam were extended to produce the longer stroke. It can also be obtained from the basic rating formula $C = \frac{8PT}{S}$ The larger of the two series C ratings is presumed to be obtained by a longer crank on the Series B unit.

Series C units for longest stroke may eventually have to be modified for smaller gear box ratings since

Table 4

API PUMPING UNIT SERIES

API REDUCER SIZE		STRUCTURE SERIES A		
Basic	Alternate	Max. Stroke In.	Structure Rating lb	API Structure Size
6.4	10	16	3,200	32-16
10	16	20	4,000	40-20
16	25	24	5,300	53-24
25	40	30	6,700	67-30
40	57	36	8,900	89-36
57	80	42	10,900	109-42
80	114	48	13,300	133-48
114	160	54	16,900	169-54
160	228	64	20,000	200-64
228	320	74	24,600	246-74
320	456	86	29,800	298-86
456	640	100	36,500	365-100
640	912	120	42,700	427-120
912		144	42,700	427-144

STRUCTURE SERIES B

Max. Stroke In.	Structure Rating lb	API Structure Size
24	2,100	21-24
	3,200	32-24
30	2,700	27-30
	4,000	40-30
30	4,300	43-30
	5,300	53-30
36	5,600	56-36
	6,700	67-36
42	7,600	76-42
	8,900	89-42
48	9,500	95-48
	10,900	109-48
54	11,900	119-54
	13,300	133-54
64	14,300	143-64
	16,900	169-64
74	17,300	173-74
	20,000	200-74
86	21,200	212-86
	24,600	246-86
100	25,600	256-100
	29,800	298-100
120	30,400	304-120
	36,500	365-120
144	35-600	356-144
	42,700	427-144
168	42,700	427-168
	42,700	427-168

STRUCTURE SERIES C

Max. Stroke In.	Structure Rating lb	API Structure Size
120	21,300	213-120
	25,600	256-120
144	25,300	253-144
	30,400	304-144
168	30,500	305-168
	35,600	356-168
192	38,000	380-192
	42,700	427-192

Structure capacity is limited to 42,700 lb by sucker rod capacity

the trend seems to be in the direction of longer stroke. If this trend continues, the standard can be amended as necessary.

The foregoing summarizes the API Pumping Unit Standard as it affects mechanical design. It is equally important that the user also be aware of the design details not covered by API standards!

(1) Geometry: this has to do with the beam center distances, samson post height, crankshaft height, pitman length, tail bearing location, etc. Each manufacturer's pumping unit has its own characteristic geometry; many are very similar; others are quite different.

(2) Bearing rating: all bearings are applied according to each manufacturer's best judgment.

(3) Stresses in shafts, pins, etc.

It is considered that these features are too complex to permit standardization, and for this reason the best assurance of reliable pumping machinery is still the reputation and experience of the manufacturer.

The API Pumping Unit Standard also contains a Recommended Practice for the Calculation and Application of Torque Factor on Pumping Units. This is a very useful tool for analyzing the torque developed at the crankshaft to determine whether the unit is being operated within its rating; but time limitations preclude an explanation of this procedure. However, it is recommended that anyone interested in this technique obtain a copy of API Standard 11E, Ninth Edition, and study Appendix B. Torque factor tables are available from most manufacturers for their units.

A final word -- the American Petroleum Institute is an oil industry organization and its activities are directed toward furthering the objectives of all oil company members. The principal objective of each member company is to make a profit for its stock holders. API standards help to achieve this objective by increasing operating efficiency. It is urged, therefore, that all operators support the API by specifying API standard equipment.

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