

[54] MINIMUM STRESSED WRENCH

[76] Inventor: Alfred Frederick Andersen, 2014
Los Angeles Ave., Berkeley, Calif.
94707

Primary Examiner—Al Lawrence Smith
Assistant Examiner—James G. Smith

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[52] U.S. Cl. 81/121 R

[51] Int. Cl.² B25B 13/06

[58] Field of Search 81/121 R

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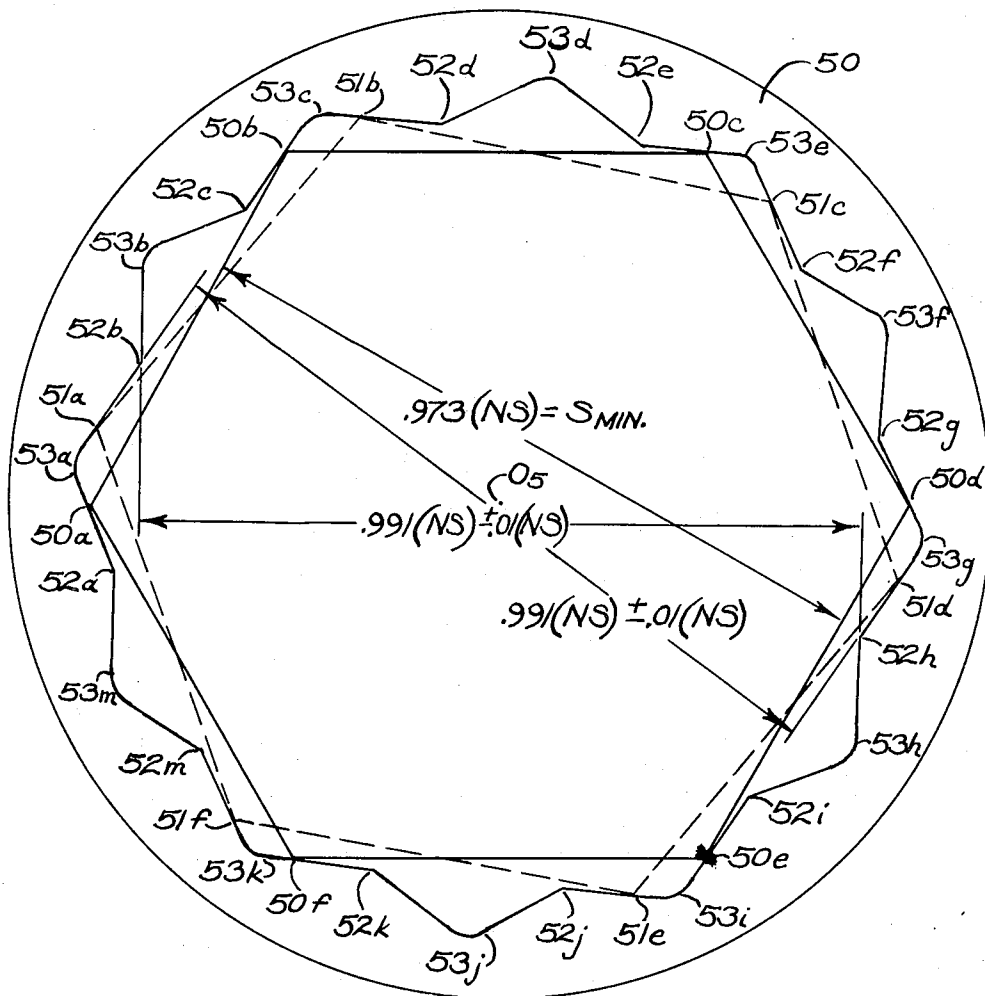
FOREIGN PATENTS OR APPLICATIONS

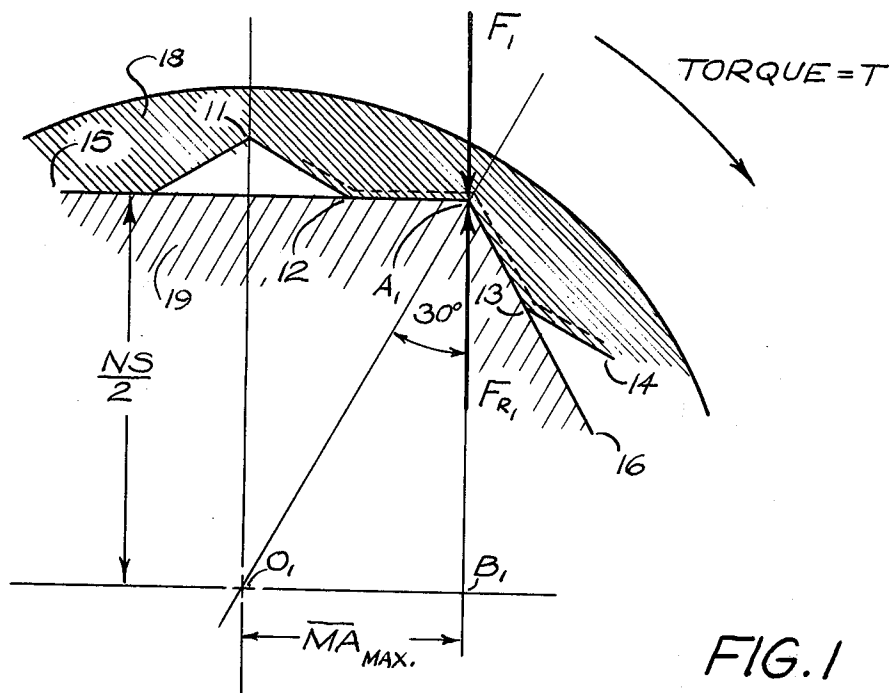
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[57] ABSTRACT

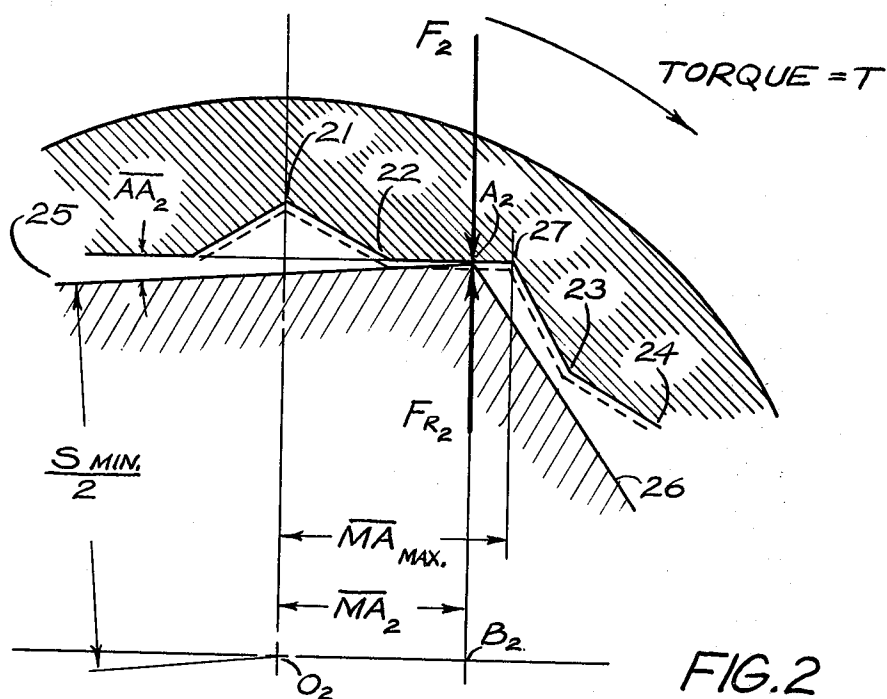
A wrench for use on polygonal nuts wherein the distance between any two opposing nut engaging wrench surfaces is greater than the distance between the two opposing surfaces of the corresponding nut engaged by the wrench, such a wrench operates so as to set up minimum reactive stress in the wrench when conditions of maximum torque prevail, and to set up minimum stress in and deformation of the nut only when conditions of minimum torque generally prevail.

4 Claims, 7 Drawing Figures

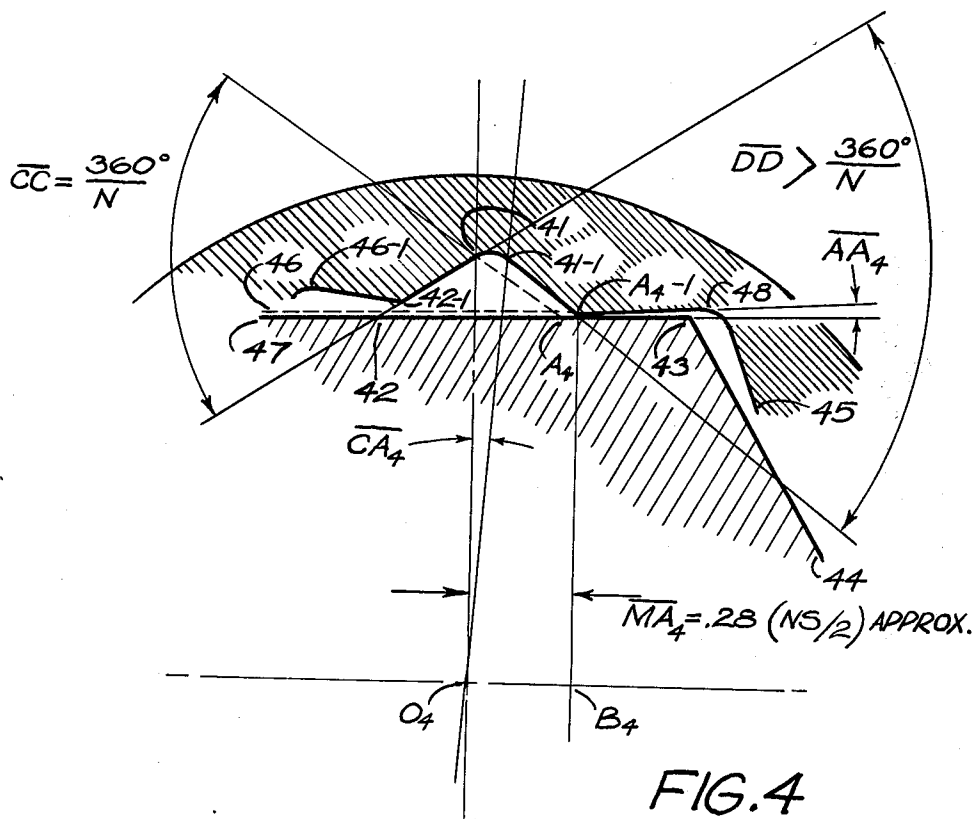
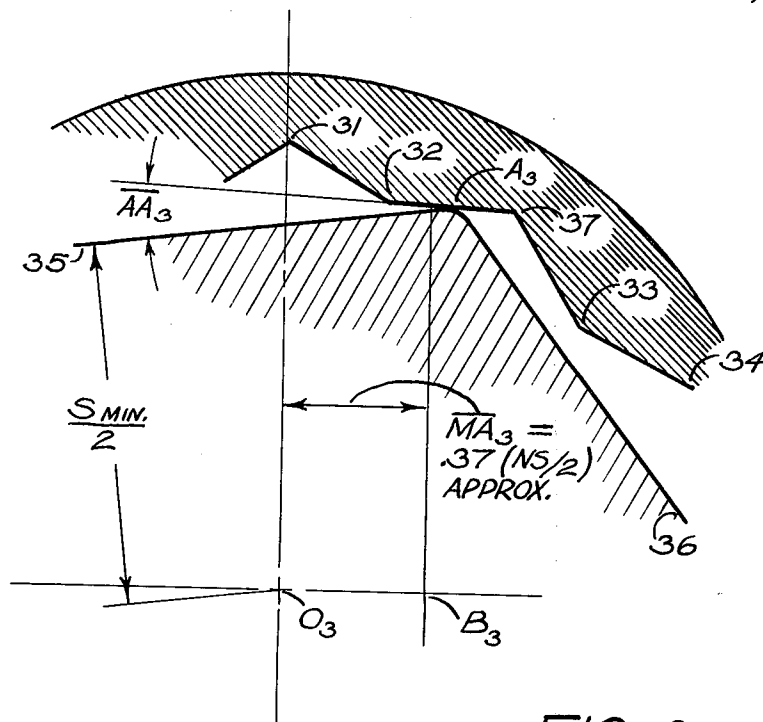


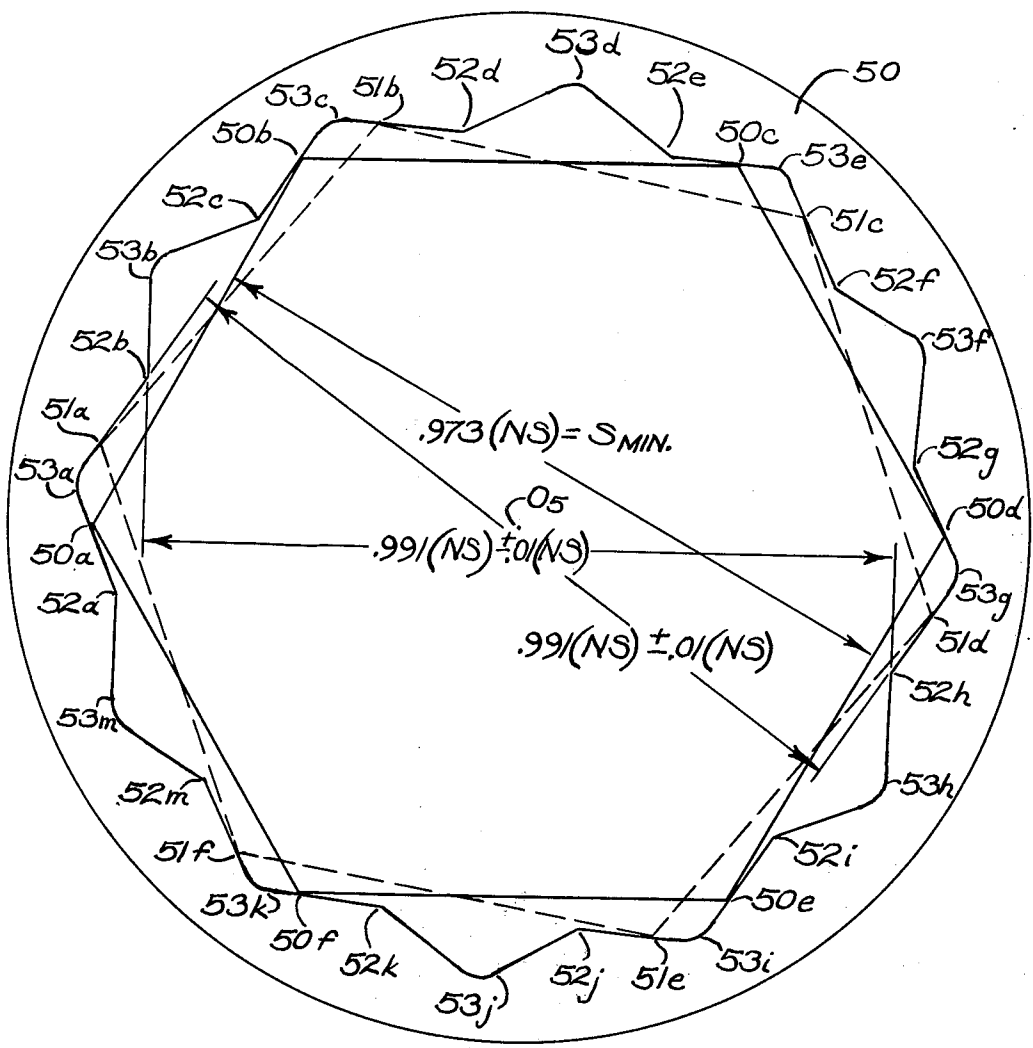


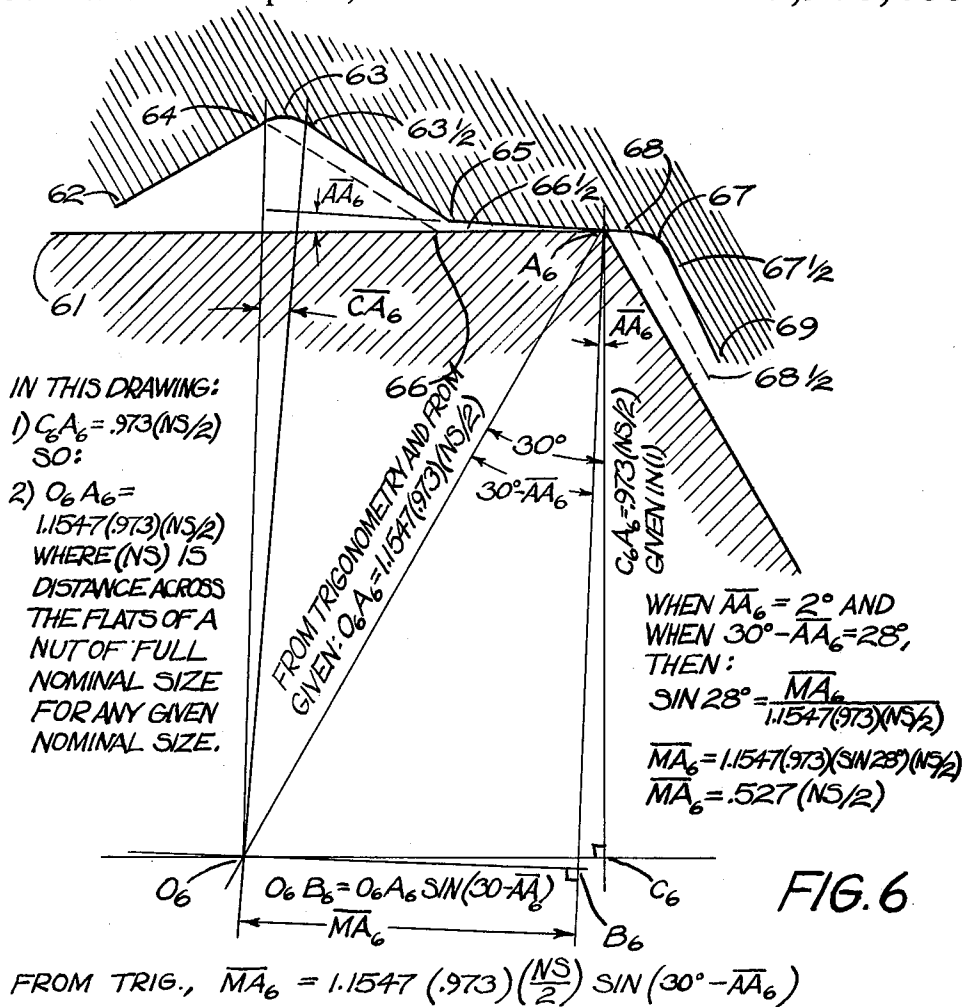
$$\overline{MA}_{MAX.} = \frac{NS}{2} (\tan 30^\circ) = .577 \left(\frac{NS}{2} \right)$$



$$\overline{MA}_2 = .48 \left(\frac{NS}{2} \right) \text{ APPROX.}$$







GENERAL CALCULATIONS :

SOLVE FOR A_6B_6

FROM DRAWING: $A_6B_6 = (O_6A_6) \cos(30^\circ - \overline{AA_6})$

FROM DRAWING: $A_6B_6 = (1.1547)(.973)(NS/2) \cos(30^\circ - \overline{AA_6})$

MULTIPLYING: $A_6B_6 = 1.123(NS/2) \cos(30^\circ - \overline{AA_6})$

AND FROM THESE EQUATIONS THE FOLLOWING TABLE #1.

	(a)	(b)	(c)	(d)	(e)
	$\overline{AA_6}$	$30^\circ - \overline{AA_6}$	$\cos(30^\circ - \overline{AA_6})$	$2(A_6B_6)$	$\overline{MA_6}$
THESE FIGURES ARE FOR $2(C_6A_6) = .973(NS)$	1	0°	.8660	.973(NS)	.561(NS/2)
	2	1°	.8746	.982(NS)	.544(NS/2)
	3	2°	.8830	.991(NS)	.527(NS/2)
	4	3°	.8910	1.000(NS)	.510(NS/2)
	5	4°	.8988	1.009(NS)	.492(NS/2)
	6	$4^\circ 42'$	.9041	1.015(NS)	.479(NS/2)
THESE FIGURES ARE FOR $C_6A_6 = .991(NS/2)$ AND $2(C_6A_6) = .991(NS)$	1a	0°	.8660	.991(NS)	.572(NS/2)
	2a	1°	.8746	1.000(NS)	.555(NS/2)
	3a	2°	.8830	1.009(NS)	.519(NS/2)

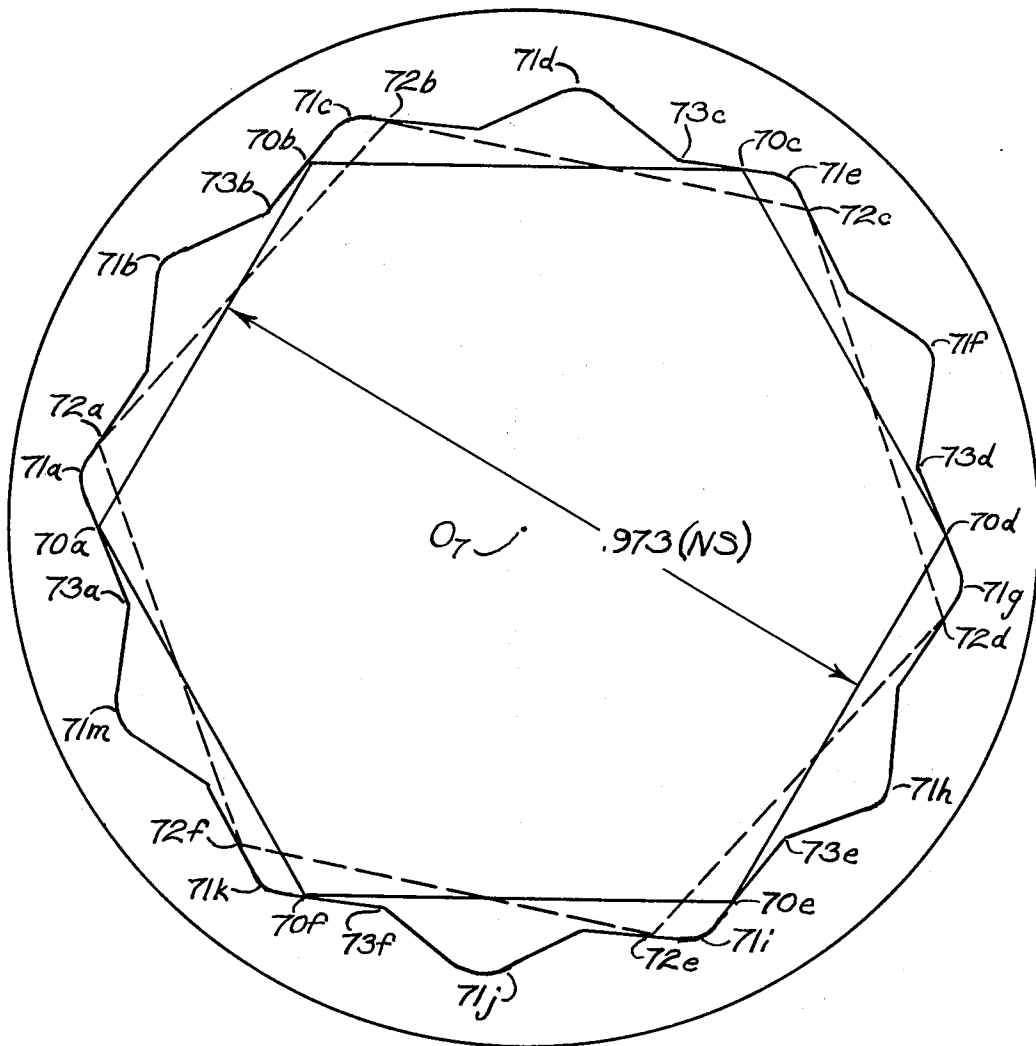


FIG. 7

MINIMUM STRESSED WRENCH

SUMMARY OF INVENTION

Over a period of a half century a wide variety of wrench designs have been proposed and used for the purpose of minimizing deformation to a nut, which deformation may occur at the corners of the nut when a wrench applies torque to the nut, the common element in these designs being to grip the nut behind the corners, i.e., on the flats.

The wrench of this invention, however, in all cases favors the wrench over the nut, and favors the nut only under those circumstances when there is no practical possibility of damaging the wrench; and this latter is the case when the wrench is employed in tightening as against loosening. For the amount of torque applied in tightening is characteristically considerably less than that torque which may at times be applied in loosening, and which latter torque any adequate wrench must therefore withstand. Thus, the wrench of this invention gives no consideration in any of its forms to nut deformation during counterclockwise turning, normally the direction of rotation employed in loosening, for during such loosening it is designed to yield the practical minimum in the ratio of reactive stress to torque in order that during times of maximum torque the wrench may be subjected to the minimum practical reactive stress. But the wrench of this invention does, in one of its forms, give consideration to nut deformation during clockwise turning, normally the direction of rotation employed in tightening, and thus of minimum torque.

It is often desirable to avoid damage to a nut during tightening, since it is desirable to preserve the original condition of the nut both for appearance sake and so that it can effectively be operated on later for loosening if necessary. On the other hand, in most situations damage to a nut during loosening is not a serious problem compared to the problem of possible breakage of the wrench, because the expense and inconvenience of having to use a new nut, if reinstallation of a nut is necessary, is far less than the expense and inconvenience of replacing a wrench if the wrench should break under the far greater torque which is often applied in loosening as against tightening, especially in loosening a corroded and entrenched nut. Also, since the strength which must be built into a wrench for the purpose of meeting maximum loosening torque is so much greater than that needed in its tightening function, a form of the wrench of this invention engages the nut in such a way as to bring about minimum deformation to the nut during tightening at the expense of a greater ratio of reactive stress to torque without thereby putting the wrench in jeopardy. Because the torque employed in tightening is generally so much less than may be employed in loosening, such as in loosening a corroded nut, a substantially greater ratio of reactive stress to torque may be permitted in the tightening direction than in the loosening direction while nevertheless resulting in a reactive stress well within the reactive stress which may be set up in loosening, and which reactive stress the wrench as a whole must therefore be made to withstand.

The principle by which the wrench of this invention assures a minimum ratio of reactive stress to torque while maximum torque is being applied is by engaging the nut in such a way that (a) minimum force is applied between the wrench and the nut, and that (b) the reac-

tive force thus applied to the wrench by the nut is at a location on the wrench such that minimum reactive stresses are set up in the wrench for any given magnitude of such reactive force.

With reference to (a) above, for any given applied torque minimum reactive force is applied to the wrench when the moment-arm by which this torque is transmitted is maximum, since for any given torque the magnitude of the force applied is inversely proportional to the magnitude of the moment-arm. This maximum moment-arm is obtained when the perpendicular distance to the line of force from the center of rotation is maximum. And this condition obtains when the wrench contacts the nut as close to the corners of the nut as practical without, however, going substantially around the corners of the nut.

With reference to (b) above, minimum reactive stress is set up in the weakest parts of the wrench when, for any given reactive force applied, the reactive force is applied at, rather than away from, the thinnest wall sections of the wrench. And, again, this minimum reactive stress is brought about insofar as the nut is engaged at the corners rather than behind the corners of the nut. Therefore, during the loosening function all forms of the wrench of this invention grip the nut as near to "at the corners" as practical without going substantially around the corners. However, as will be shown, all forms of the wrench of this invention do characteristically go around the corners to some extent, in any case during loosening, in order to avoid an even worse condition for the wrench, that of gripping substantially behind the corners. This requires somewhat lengthy explanation.

HISTORICAL PERSPECTIVE

It has long been a limitation of conventional wrenches that they tended to both round the corners of the nuts they engaged and simultaneously set up severe wedging forces tending to fracture the wrench. As indicated above, historically the main concern has been with deformation to the nut rather than fracture of the wrench, perhaps because wrench fracture could be prevented simply by increasing the wall thickness of the wrench. Furthermore, it may have been felt that any problems with the wrench generally resulted more from the rounded corners on the nut than vice versa. In any case, emphasis in wrench designs historically has been on how to prevent rounding the corners of the nut.

The problem of how to prevent such rounding was largely met by constructing wrenches which completely surround the nut, such as is the case with socket and box wrenches, for these are not subject to spreading as are open-end wrenches. In fact, there is generally no problem in rounding the corners of a nut while using a wrench of the box or socket wrench type.

As for open-end wrenches themselves, the problem could, of course, have been partially solved by making a closer fit between the wrench and the nut, for rounding is most likely to take place when an oversized wrench engages an undersized nut. And today the ANSI Standards specified by the American National Standards Institute, having replaced the American Standards Association in setting accepted trade standards, specify tolerances on both wrenches and nuts which are closer than at times in the past. But holding close tolerances increases manufacturing costs, and there is a practical limit beyond which it is very expen-

sive to go. Also, still referring to open-end wrenches, there remained the problem of rounding when a wrench with an opening at the upper dimensional limit met a nut with dimensions at the lower limit. And even when the smallest wrench met the largest nut there had to be sufficient difference between the two to allow easy engagement and disengagement. But, most important of all, since the conventional open-end wrench is by nature subject to spreading under torque, even the best of fit between wrench and nut tends to become loosened, and to begin rounding, as substantial torque is applied.

So this persistence of the problem for open-end wrenches suggested another approach. Instead of providing clearance for engagement and disengagement in the conventional way, an innovation was put forth whereby clearance was provided by angular displacement rather than linear displacement. That is, instead of providing such clearance by increasing the perpendicular distance between the wrench's opposing gripping faces, the portions of the wrench used in loosening were physically rotated in relation to the portions of the wrench used in tightening. Since the problem of getting clearance for engagement and disengagement has never been that there was a clearance problem within the functions of the tightening portion as a unit, or within the functions of the loosening portion as a unit, but rather that the functions of the loosening portions and the functions of the tightening portions interfered with each other, this innovation of angular clearance completely removed the problem of clearance referred to above. Thus, substituting angular clearance for linear clearance made it possible to have a wrench which engaged the nut well behind the corners in both tightening and loosening without these two distinct functions' interfering with each other. In what follows I will refer to the angle of rotation of the tightening portions in relation to the loosening portions as employed in providing angular clearance as "the clearance angle."

There were at least three reasons why said innovation has not become popular in the open-end wrench, the wrench to which it was first applied. One was hesitant trade acceptance due to its strange appearance, another the fact that box wrenches and socket wrenches have already gone a long ways toward meeting the problem of rounding the corners of nuts, and finally, in view of these reasons, the questionable justification for the expense of retooling and for educating the trade as to the advantages of the new configuration.

And thus the matter has largely rested until the present day. There have been a number of variations on the themes mentioned above. For instance, there have been recent designs applying the principle of angular clearance to the socket-type of wrench as well as to the open-end type. But these designs have all employed the angular displacement principle exclusively as a means of always gripping the nut behind the corners (i.e., on the flats), and since there is a little problem in rounding corners with socket wrenches because of their inherent resistance to spreading, these designs have not offered a practical advantage over conventional socket and box wrenches; in fact, as will be explained, they were inferior to conventional sockets because in gripping the nut behind the corners the moment-arm by which torque was transmitted to the nut was substantially reduced and the accompanying reactive stress set up in the wrench was substantially increased, thus making this

type of socket wrench substantially more liable to fracture than the conventional socket wrench. The reason this disadvantage was overlooked is evidently because the application of angular clearance to socket-type wrenches has always been incidental to the basic and primary application to open-end wrenches. There have been claims of socket-type wrenches employing this angular clearance principle in engaging the nuts behind the corners that they made for less stress in the wrench as well as less deformation of the nut. But such is not the case, for the reason mentioned above and for reasons more fully set forth below. Presumably, if concern for the wrench rather than the nut had been primary this error would have been discovered, in tests if not in theory.

In any case, there has not up to this time been an adequate effort to utilize the principle of angular clearance in combination with, and in order to make practically feasible, a wrench design of the socket-type which at all times favors the wrench over the nut, or which favors the nut only when there is no practical danger of injury to the wrench. The wrench of this invention does precisely this. It incorporates angular rotation of tightening portions of the wrench in relation to loosening portions as the means of providing clearance between these two portions for engagement and disengagement, but its inventiveness consists in employing a set of dimensional relations such that the manner of engaging the nut or bolt-head under maximum torque results in the minimum practical ratio between reactive stress in the wrench and applied torque.

Put another way, in the wrench of this invention, being only secondarily concerned with deformation to the nut, and primarily with reactive stresses in the wrench, the primary objective is to go between the horns of a dilemma, the one horn being a reduced moment-arm resulting from going around the corners of the nut, and the other horn being a reduced moment-arm resulting from engaging the nut behind the corners and on the body of the nut faces.

In what follows it will be shown that in order to accomplish this objective the angles which the wrench-faces make with the nut-faces must be held within quite definite dimensional limits; and it will be shown that a very small change in these angular relationships can have a substantial effect on whether the nut is or is not gripped behind the corners, and thus on the moment-arm by which a given applied torque is transmitted to the nut, and thus further on the reactive forces and reactive stresses set up in the wrench. It is for this reason that said definite limits of said angular relationships, in turn accomplished by close dimensional relationships between certain dimensions in the wrench and certain nominal sizes and tolerances specified by such standards as the ASNI Standards referred to above, constitute the essence of the inventiveness of the wrench of this invention.

The wide manufacturing tolerances allowed by the trade for nuts and bolts complicates the problem of specifying these definite limits. Because of these tolerances and the need for practical manufacturing tolerances on the wrench as well it is impossible to provide a wrench which, for any nominal size (whether $\frac{1}{2}$ inch, etc.), engages in the ideal way each and every allowed variation from the nominal size. Therefore, the wrench of this invention provides for optimum engagement over an allowable and practical range rather than for

ideal engagement of the nominal size only; and an important part of the specifications of this wrench is the specification of practical manufacturing tolerances in the crucial dimensional relationships which are determining of said crucial angular relationships.

As has been implied above, there is yet another factor which enters into the determination of said optimum. The angular relationships between wrench-faces and nut-faces which concern us are not those which exist at mere torque, rather at maximum torque, for it is during maximum torque that wrench breakage will occur if at all. And there is a difference as regards said angular relationships. For under maximum torque both the wrench and the nut, under strain, take a different shape than under zero torque. For instance, a wrench which while under zero torque engages a given nut behind the corners and substantially on the nut faces (as against "at the corners") may well engage the same nut "at the corners" while under maximum torque, the change being the result of changes within both the nut and the wrench. And, since the reactive stress which concerns us is that set up at maximum torque, the angular relationships which concern us are those which occur under maximum torque, and it is these particular angular relationships which are determining of the dimensional relationships specified by the wrench of this invention and determining of its inventiveness.

In what follows it will be shown that a wrench of this invention, as with conventional box and socket wrenches, has two sets of gripping faces, one set used in tightening (normally clockwise) and another set used in loosening (normally counterclockwise). It will also be shown that for any given nut or bolt meeting standards accepted in the trade, such as ANSI Standards, the perpendicular distance between any two opposing faces of the wrench has a direct consequence for the crucial angles formed between said wrench-faces and nut-faces. Therefore, the wrench of this invention is characterized by certain precise relationships between (a) the perpendicular distance between opposing wrench-faces and (b) the nominal sizes of the nuts and bolts it is sized to engage. These relationships in turn are determining of the maximum practical moment-arm employed in transmitting applied torque, and thus of the minimum reactive stresses set up in the wrench, and of the greater durability of a wrench of given wall thickness or of the wall thickness needed to assure a wrench of given durability.

IN SUMMARY

It is an object of this invention to provide a wrench of the socket and box wrench types which engages nuts and bolts in such a way that there results in the weaker sections of the wrench the practical minimum ratio of reactive stress to applied torque at the time of maximum applied torque, while giving only secondary consideration to damage to said nuts and bolts.

It is a further object of this invention to provide a wrench of the socket and box wrench types which engages nuts and bolts in such a way that, for any given applied torque, the reactive stresses set up in the weaker sections of the wrench during loosening are substantially less than those set up during tightening.

It is a further object of this invention to provide a wrench which engages nuts and bolts in such a way that no nut or bolt which falls within accepted trade tolerances, such as provided by ANSI Standards, will be en-

gaged behind the corners and substantially on the flats at the time of maximum deflection under maximum torque; rather all such nuts and bolts will be engaged, at such times of maximum torque, either at or slightly around the corners, so as to give optimum consideration to setting up minimum reactive stresses in the weaker portions of the wrench during such times of maximum torque.

It is a further object of this invention to grip the nut in such a way that maximum use is made of the maximum moment-arm attainable with any particular nut, thus resulting in minimum force on the nut for any given nut and any given applied torque, but, what is more important, resulting in minimum force on the wrench and minimum tendency to fracture the wrench.

Another purpose of this invention is to provide a wrench which grips the nut over a maximum surface area during the gripping period when torque is maximum, and thus when force is maximum, thus reducing to the minimum the tendency to distort the nut being engaged and the wrench doing the engaging.

A further object of the wrench of this invention is to provide a wrench in which it is possible to avoid sharp corners in the internal cavity of the wrench, where stress concentrations tend to build up, and to do so without sacrificing any other feature of good wrench performance and without any abruptness in the contour wrench the wrench cavity.

A further object of this invention is to provide a wrench wherein the acute angle formed by the perpendiculars to any two adjacent gripping surfaces where the obtuse angle formed by these surfaces opens away from the center of the wrench cavity is, for a 12-point socket, something greater than 30°, and where the above-mentioned obtuse angle is, also for a 12-point socket wrench, something less than 150°; and with corresponding angular relationships for the 18-point and the 24-point sockets.

A further object of this invention is to provide a wrench wherein the perpendicular distance between the planes of any two opposing wrench flats, those used for engaging the nut faces, is something less than the nominal distance between the faces of the nut which the wrench is designed to engage.

A further object of this invention is to provide a wrench which, while containing all the advantages appreciated by the sophisticated wrench user, has an appearance which will be acceptable to the unsophisticated wrench user, thus making possible maximum sales volume and minimum cost per unit.

A further object of this invention is to provide a wrench wherein the hardened punch used to punch out the wrench cavities is considerably less subject to significant wear, thus greatly reducing tooling costs per unit wrench, because of having no sharp corners subject to rapid wear.

A further object of this invention is to provide a wrench in which the "approach angles" employed in tightening a nut or bolt may be different from those employed in loosening, where by "approach angle" is meant the angle formed between a face of the wrench and the face of the nut engaged in said wrench face.

THE DRAWINGS

FIG. 1 shows a section of a conventional 12-point socket engaging a section of a regular hexagonal nut in perfect fit, with no clearance to engage and disengage.

FIG. 2 shows a section of a conventional socket engaging a nut in a loose fit.

FIG. 3 is the same as FIG. 2 except that the nut is shown with a considerably rounded corner.

FIG. 4 illustrates the principle of angular clearance in providing clearance for engagement and disengagement.

FIG. 5 shows a wrench of this invention engaging a nut of minimal size within the nominal.

FIG. 6 shows how the specifications of this invention are arrived at.

FIG. 7 shows a preferred form of the wrench of this invention with tightening grip different from loosening.

THE DRAWINGS IN DETAIL

FIG. 1 shows a perfect fit, which could not exist in practice because the lack of clearance would prevent engagement and disengagement. The surface identified by 15, 11, 12, A_1 , 13, 14 is a section of the internal gripping surfaces of the wrench, with subsurfaces 12, A_1 , and 13, 14 positioned to grip in clockwise turning and subsurfaces 11, 12 and A_1 , 13 positioned to grip in counterclockwise turning. The section of nut is identified by 15, A_1 , 16.

The symbol NS signifies "Nominal Size," whether $\frac{1}{2}$ inch, $\frac{3}{4}$ inch, or some metric nominal size, where the nominal size referred to is, in the case of a nut or a bolt, the nominal perpendicular distance across any two opposing flats of the nut or bolt, and, in the case of the wrench, is the nominal perpendicular distance separating any two opposing gripping faces, and where the term "nominal" refers to that dimension referred to by any standard accepted in the trade, such as ANSI Standards, in specifying manufacturing dimensions and tolerances acceptable in practice in the trade. Since it would be impossible for a conventional socket wrench of exact nominal size (such as 0.8750 inches) to engage and disengage a nut or bolt of the same exact nominal size, the American National Standards Institute has set ANSI Standards such that the conventional wrench opening is specified to be always greater than nominal and the perpendicular distance across the flats of nuts and bolts to be always less than nominal. More precisely, ANSI Standards call for conventional wrench openings to be greater than NS but less than a figure which, though varying with the particular nominal size, roughly complies with the formula $1.02(NS)$. Thus, the ANSI Standard for conventional wrench openings is roughly $1.01(NS)$ plus or minus $0.01(NS)$. These dimensional relationships are crucial to assure the workability of conventional socket wrenches. Similarly, it will be shown that the wrench of this invention is characterized by a comparable set of dimensional relationships, but as applied to a wrench employing angular clearance rather than linear clearance.

Still referring to FIG. 1, the dimension $NS/2$, the perpendicular distance from the center of the nut and wrench cavity to any of the nut-faces or wrench-faces of the nominal sized nut or wrench, represents half of NS. Thus, the moment-arm by which applied torque would be transmitted is seen to be, applying trigonometry to triangle $O_1 A_1 B_1$, $(NS/2) (\tan 30^\circ)$, or $0.577(NS/2)$, as shown; and this is the maximum moment-arm possible (identified as $\overline{MA}_{max}$) in any engagement with any hexagonal nut of any nominal size without digging into the faces of the nut as a way of

moving out from the center the line of direction of the force by which the torque is transmitted.

FIG. 2 also shows a section of a conventional 12-point socket wrench engaging a section of a regular hexagonal nut, but in this case the fit is not surface-to-surface, but surface-to-line. The gripping surfaces of the wrench section are identified by 21, 22, A_2 , 27, 23, 24. The surfaces of the nut are identified by 25, A_2 , 26. The line of contact between the wrench and the nut is identified by A_2 . The dotted lines identify the nominal size of the wrench, which, as shown in solid lines, is near the upper limit of ANSI wrench tolerance, and the nut, drawn to the same scale, is near the lower limit of ANSI nut tolerance, the perpendicular distance between any two opposing faces being identified as S_{min} .

Thus we see the condition which exists in a conventional socket when a near-extreme condition of misfit exists. It can be seen that the moment-arm, identified as $\overline{MA}_2$, by which the torque is transmitted from the wrench to the nut, and which in turn has an effect on the reactive force exerted by the nut on the wrench, is substantially reduced from the maximum of $0.577(NS/2)$. By scale measurement the reduction is estimated to be $0.48(NS/2)$ approximately, as shown. It can also be seen that as torque is applied and the corner of the nut breaks down that this moment-arm will be reduced still further, and may eventually approach the greatly reduced amount shown in FIG. 3. However, in general, the damage to the nut, even in this extreme position, is minimal compared to the possible damage to the wrench. For any reduction in moment-arm, such as is shown to occur in this case, substantially increases the force reacting on the wrench, in this case at A_2 , and this substantially increases the reactive stresses in the wrench and the tendency to fracture the wrench.

Also, the greater the distance between A_2 and the nearest thin section of the wrench, at 27, the greater the stress set up at the weak points in the wrench, such as at 27, even if the reactive force were to remain the same. In short, the movement of A_2 away from 27 serves to increase the stress at 27 because of the movement itself entirely apart from the increased reactive force resulting from reduction, due to such movement, in the moment-arm. And insofar as there exists a sharp corner at 27, as is characteristically the case in the case of a conventional socket wrench, the accumulated stress tends to be concentrated and intensified, and thus greatly contributes to the tendency for the wrench to fracture. All three of these contributors to the tendency for the wrench to fracture are greatly reduced in the wrench of this invention.

FIG. 3 shows the same situation as in FIG. 2 except that the corners of the nut are shown to be substantially rounded and that the moment-arm is shown to be further reduced, this time to approximately $0.37(NS/2)$, and that the line of contact between the wrench and the nut, in this case identified by A_3 , is even farther removed from the nearest thin section of the wrench, in this case identified by 37, both of which factors contribute further to the tendency for wrench fracture at a thin section, such as at 31 and 37, and both of which factors result from a rounding of the corner of the nut as shown.

Since this amount of rounding of the nut is not unusual, it can be seen that whereas conventional box and socket wrenches contribute only minimally to further rounding of the corners of a nut, they may at times be

subjected to tremendous accumulated and concentrated stress due to rounding which takes place by other means or due to manufacturing tolerances which are practically necessary in conventional configurations in order that such wrenches can readily engage and disengage and in order that manufacturing costs are not inordinately high.

FIG. 4 shows how using what I have called angular clearance, as distinct from linear clearance, makes it possible to have a wrench which at all times, and for all variations within nut sizes within ANSI Standards for any given nominal size, grips the nut behind the corners, and thus completely avoids any tendency to round the corners of the nut.

In FIG. 4, a cross-section of portions of two faces of a nut of minimal ANSI dimensions for an nominal size is identified by 47, 42, A_4 , 43, 44. The interior gripping subsurfaces of the wrench are identified by 46-1, 42-1, 41-1, A_4 -1, 48, 45. The subsurface A_4 -1, 48 of the wrench is shown engaging nut subsurface 47, 43 along a line identified by A_4 -1 and positioned for turning the nut in clockwise rotation. Of the wrench section shown, the other subsurface positioned for clockwise turning is identified by 42-1, 41. On the other hand, the subsurfaces positioned for counterclockwise turning are identified by 41-1, A_4 -1 and 46-1, 42-1. These latter two subsurfaces occupy the positions shown rather than the positions indicated by dotted lines 41, A_4 and 46, 42 as the result of what I have called angular clearance. If the subsurfaces for engaging in counterclockwise turning were positioned as shown by the dotted lines, engagement and disengagement would be impossible. But by rotating subsurfaces 41, A_4 and 46, 42 about central point O_4 by an angle which I will call the clearance angle, and identified by CA_4 , the clearance for engagement and disengagement shown between A_4 and 42-1 is generated. It can be seen that if the wrench is then rotated counterclockwise through this same angle, CA_4 , that subsurface 46-1, 42-1 will fall along the dotted line 46, 42, and will therefore be in position to turn the nut counterclockwise by the same approach angle, AA_4 , with which subsurface A_4 -1, 48 approaches nut subsurface 47, 43. Whereas, from the geometry of regular polygons, it follows that the magnitude of the acute dihedral angle formed in a conventional box or socket wrench by the intersection of the plane of any subsurface for turning a nut in clockwise rotation, such as subsurface 42, 41, and the plane of that adjacent subsurface for turning said nut in counterclockwise rotation which engages the nut in the vicinity of the same vertex of the nut as said "any subsurface," here shown as subsurface 41, A_4 , is equal to the quantity 360° divided by the number (n) of sides in the polygon, which in FIG. 4 would be the quantity $360^\circ/6$, or 60° , and shown in FIG. 4 as dihedral angle CC , the magnitude of the comparable dihedral angle in a wrench employing angular clearance, and shown in FIG. 4 as dihedral angle DD , is necessarily and characteristically something greater than $360^\circ/n$, and, in the case of an hexagonal nut, something greater than 60° .

As noted above, the utilization of angular clearance was instituted historically primarily in order that nuts could be gripped behind the corners as against around the corners. This practice had genuine utility value as applied to open-end wrenches, for open-end wrenches would then spread to provide ideal surface-to-surface contact. But it can now be seen why this unthinking ap-

plication to socket and box wrenches has not proved practical. For in FIG. 4 it can be seen that the moment-arm by which torque is transmitted is very greatly reduced by this approach, and that the location at which reactive force is applied is further removed from the thin section of the wrench wall, both of these factors contributing to increased reactive stress at the weak points of the wrench, for instance at 41 and 48.

From FIGS. 1, 2, 3, and 4 it can be seen that a relatively small change in the dihedral angle with which a gripping subsurface of the wrench approaches the face of a nut to be gripped can have a very substantial effect on the reactive stresses set up in the wrench, and on the resultant tendency for the wrench to fracture. It is, of course, possible to resist this tendency by substantially increasing the wall thickness of the wrench, but such increase increases in turn the cost of materials from which the wrench is fabricated and increases also the amount of clearance required for the wrench to function in tight places. Therefore, for any given strength requirement it is desirable to make the wall thickness of a socket or box wrench as thin as possible, and such is precisely what the wrench of this invention makes it possible to do.

Referring to FIG. 4, for instance, it can be seen that if the approach angle AA_4 were reduced by only a couple of degrees there would be contact with the nut "at the corners" without going "around the corners," and yielding thereby both maximum moment-arm and closest proximity to the thinnest wall-section of the wrench, both of which would contribute to minimum reactive stress at the thinnest wall sections 41 and 48. It is for this reason that the precise identification and specification of those dimensional relationships which result in those approach angles between wrench and nut subsurfaces which assure minimum ratio of reactive stress to torque during maximum torque, which the wrench of this invention provides, constitutes a significant innovation in wrench designs.

FIG. 5 shows a cross-section of a typical 12-point socket wrench of this invention engaging, also in cross-section, an hexagonal nut, where the perpendicular distance across opposing flats of the nut is close to the low limit specified by ANSI Standards, specifically 0.973(NS). The nut is shown in two positions; the one position, shown in solid lines, with vertices identified by 50_a, 50_b, 50_c, etc., is where the nut is in position to be turned by the wrench in clockwise rotation; the other nut position, shown in dotted lines, with vertices identified by 51_a, 51_b, 51_c, etc., is where the nut is in position to be turned by the wrench in counterclockwise rotation. The dimension across opposing gripping subsurfaces, such as subsurfaces 52_b, 53_b, and 52_a, 53_a, shown as approximately 0.991(NS) plus or minus 0.01(NS) is that dimension which will be specified of that form of a wrench of this invention which is designed to grip nuts of mild steel, as opposed to heat treated steel or soft metals. In discussing FIG. 6, it will be shown how this invention's specifications of dimensional relationships are arrived at for various forms of the invention.

Finally, as regards FIG. 5, it can here clearly be seen that this invention employs what I have called "angular clearance" in order to provide clearance between the clockwise-turning and the counterclockwise-turning portions of the wrench, a principle which has been borrowed from the prior art and for which this invention makes no claim of originality. The originality of this in-

vention, rather, lies in relational specifications over and beyond the concept of angular clearance, and precisely in what way this is the case will be further clarified in discussing FIG. 6 below.

FIG. 6 shows what moment-arms result from each of various dihedral angles of approach between the gripping subsurfaces of each of various possible specifications of wrenches of this invention and the faces of a nut to which torque is being applied. It also shows what are the relative dimensions of the perpendicular distances between opposing gripping subsurfaces on the wrench which must be specified in order to bring about these various approach angles. From this information it then becomes possible to specify for a wrench of this invention certain relational dimensions and tolerances for the perpendicular distances between opposing gripping subsurfaces for any nominal size and for various forms of wrenches of this invention in consideration of the hardness of the nuts to be engaged.

As in FIG. 2 through 5, the nut whose section is shown is, for any given nominal size, of a dimension across any two opposing gripping subsurfaces near the low limit allowed by ANSI Standards, namely 0.973 (NS), thus making the perpendicular distance from the center of the nut to any side of the nut, C_6A_6 , equal to $0.973(NS/2)$, as shown. In right triangle $O_6C_6A_6$, since angle $O_6A_6C_6$ equals 30° , side O_6A_6 equals $C_6A_6 \sec 30^\circ$, or $1.1547(0.973)(NS/2)$, as shown.

A section of a wrench of this invention is shown in solid lines identified by 62, 63, 65, 67, 69, and the line of contact between the wrench subsurface and the nut face is identified by A_6 , the wrench being positioned to turn the nut in clockwise rotation. In a conventional socket configuration the adjacent wrench subsurfaces, those used for turning the nut in counterclockwise rotation, would fall along dotted lines 64, 66 and 68, 68½, but in order to provide angular clearance the comparable faces on a wrench of this invention, those used for turning a nut in counterclockwise rotation, are at an angular clockwise rotation of $\bar{C}A_6$, as shown, from the conventional positions; thus, what would be position 64 on the conventional wrench becomes 63½, as shown, and what would be 68 on the conventional wrench becomes 67½, as shown. And this angular clearance makes possible the characteristic blending radius at root positions indicated by 63 and 67, thus reducing the possibility of stress concentrations at these positions.

The approach angle between the wrench subsurfaces, such as subsurface 65, 67, and the nut faces, such as 61, A_6 , is identified as $\bar{A}A_6$, and the force exerted on the nut by the wrench, as well as the reactive force exerted by the nut on the wrench, is, assuming no significant friction between the surfaces, along the direction A_6B_6 , and the moment-arm ($\bar{M}A_6$) by which torque is transmitted is thus O_6B_6 , the perpendicular distance from O_6 to A_6B_6 , and is equal to $1.1547(0.973)NS/2 \sin(30^\circ \text{ minus } \bar{A}A_6)$, as shown.

Still referring to FIG. 6, the distance A_6B_6 represents half the perpendicular distance between opposing gripping subsurfaces on any wrench of this invention. Again applying trigonometry, this time in triangle $O_6B_6A_6$, it is shown that A_6B_6 equals $1.123(NS/2)\cosine(30^\circ \text{ minus } \bar{A}A_6)$, and $2(A_6B_6) = 1.123(NS)\cosine(30^\circ \bar{A}A_6)$.

Applying these mathematical expressions for various approach angles, we get, in the first six lines of Table 1, the expressions for $2(A_6B_6)$ and $\bar{M}A_6$ shown in col-

umns (d) and (e) respectively, where $2(A_6B_6)$ represents the perpendicular distance across any two opposing gripping subsurfaces of a wrench of this invention.

Focusing our attention on columns (d) and (e) of the first six lines of Table 1, the column (d) specifications for wrenches of this invention will be those which will yield the greatest practical values for $\bar{M}A_6$ in column (e), considering trade variations in nut and bolt sizes, degrees of hardness in nuts and bolts, and practical manufacturing tolerances for wrenches of this invention.

It is important to note, in the first 6 lines of Table 1, that the approach angles listed in column (a) are approach angles relative to a nut which is near the low limit of ANSI Standards, namely 0.973(NS). Thus, if this same wrench were to be engaged on a nut with a perpendicular distance across the flats of, for instance, 0.991(NS), to which the figures in lines 1a, 2a, and 3a apply, the approach angles would be quite different. For instance, it will be noted that the wrench opening, as indicated in column (d), is the same in line 3 as in line 1a, yet the approach angle in the former is 2° and in the latter 0° , a reduction of 2° . There is a similar reduction of 2° in comparing lines 4 and 2a, even though the value in column (d) is the same (1.000[NS] in each case; and similarly in comparing lines 5 and 3a. In short, when the nut size is increased by 0.018(NS) the approach angle is reduced by 2° . Thus, if the nut size were to be increased by 0.027(NS) the approach angle would be decreased by 3° , since it can be seen that there is a reduction in approach angle of 1° for each increase of 0.009(NS) in $2(C_6A_6)$, assuming the wrench size, as indicated in column (d), remains constant.

Similarly, with the nut size rather than the wrench size remaining constant, for every 0.009(NS) increase or decrease in $2(A_6B_6)$, (wrench size), the approach angle, for any given nut size, is respectively increased or decreased by 1° .

If I were to specify a value for $2(A_6B_6)$, column (d), of 0.973(NS), such a wrench would have an approach angle of zero degrees in engaging a nut of 0.973(NS) perpendicular dimension across the flats, this situation being shown in line 1. So in engaging a nut 0.018(NS) larger, namely, 0.991(NS), the approach angle would be 2° less, or minus 2° ; and in engaging a nut 0.027 larger, namely, 1.000(NS), the approach angle would be 3° less or minus 3° .

But a minus approach angle results in gripping the nut behind the corners, and thus, as shown in FIG. 4, in greatly reducing the moment-arm. Such reduction in moment-arm cannot be tolerated in a wrench of this invention, nor, therefore, can such a negative approach angle, unless such an approach angle would be increased to zero or more in the course of applying maximum torque, for it is during the period of maximum torque that any wrench of this invention must have an approach angle equal to or greater than zero.

There are two ways in which the application of torque can affect the approach angle. One is by spreading the wrench, and the other is by indenting the nut. Not much change in approach angle can be expected due to spreading of a heat-treated and hardened wrench, considering the wrench in question is totally enclosed and that it has been determined above that it would take a spread of 0.009(NS) in the wrench to change the approach angle by 1° . This amount of spreading simply doesn't take place in a heat-treated

and hardened wrench of the enclosed type. It can be shown by calculations with Youngs Modulus of Elasticity and formulas for elongation that, assuming the shape of the wrench remains the same, the increase in the dimension $2(A_6B_6)$ would be a maximum of 0.001(NS). However, the shape of the wrench would not remain the same, and tests suggest that the combination of change of shape in a hardened wrench and indentation and change of shape in a hardened nut may totally make for a change in approach angle of one degree under maximum torque.

Therefore, if we are to have an approach angle greater than zero under maximum torque and while engaging the largest nut of any nominal size, namely, 1.000(NS), the approach angle while engaging such a nut under zero torque must not be algebraically less than minus 1° ; and this would make an approach angle of 2° in engaging a nut of minimum ANSI dimension, namely, 0.973(NS), as shown in line 3 of Table 1, thus yielding, while engaging this minimum-sized nut, a moment-arm (see column [e]) of $0.527(NS/2)$ under zero torque and an estimated $0.510(NS/2)$ under maximum torque. Still discussing the form of the wrench of this invention designed for engaging heat-treated and hardened nuts, it is clearly evident from Table 1 that the greatest moment-arm and least reactive stress is attained at the smallest approach angle short of becoming negative. Therefore, it follows from the above that the specification for the form of the wrench of this invention designed to engage heat-treated and hardened nuts, for the dimension $2(A_6B_6)$, column (d), should be 0.991(NS) as a minimum; and since manufacturing tolerances totaling about 0.02(NS) must be allowed, the indicated specification for the $2(A_6B_6)$ dimension becomes 1.000(NS) plus or minus 0.009(NS), or, rounding off, plus or minus 0.01(NS), which is roughly the same as the current ANSI tolerances referred to in discussing FIG. 1.

In the case of nuts and bolts of mild steel, where a substantial amount of indentation can be expected under maximum torque, the amount of change in approach angle will be roughly an additional degree. Therefore the $2(A_6B_6)$, column (d), specification for the form of the wrench of this invention for engaging nuts and bolts of mild steel is indicated to be 0.991(NS) plus or minus 0.01(NS).

In the case of nuts and bolts of soft metal (such as brass and aluminum) further indentation makes possible a further degree change in approach angle. Therefore, the $2(A_6B_6)$, column (d), specification for the form of the wrench of this invention for engaging nuts and bolts of soft metal will be 0.982(NS) plus or minus 0.01(NS).

FIG. 7 shows an asymmetric form of the wrench of this invention, where the approach angle during clockwise engagement and turning is substantially different from the approach angle during counterclockwise engagement and turning, this being so because the perpendicular distance between the wrench's gripping subsurfaces employed in clockwise turning is substantially different from the perpendicular distance between the wrench's gripping subsurfaces employed in counterclockwise turning.

In FIG. 7, as in FIGS. 2 through 6, the nut which is shown has a dimension across the flats near the low limit as specified by ANSI Standards. Thus, as an example only, there is shown a substantial approach angle in

counterclockwise turning, where the nut is shown in dotted lines, and an approach angle of virtually zero in clockwise turning, where the nut is shown in solid lines. Thus, if this same wrench were to be shown engaging a nut of full nominal size the approach angle in counterclockwise turning would be near zero while the approach angle in clockwise turning would be negative; that is, in clockwise turning the nut would be gripped behind the corners, in order to completely remove the possibility of rounding the corners of the nut. The reason this can be done without endangering the wrench, considering the consequence of reduced moment-arm and increased ratio of reactive stress to torque, is, as stated above, that in clockwise turning, normally the tightening direction of rotation, the amount of torque which is applied is generally far less than that for which the wrench must be designed in loosening. Thus, in the tightening direction of rotation a sacrifice in the ratio of reactive stress to torque can safely be made in order to favor the corners of the nut. The amount of difference between those portions of the wrench used in tightening and those used in loosening will vary according to application.

I claim:

1. A wrench for turning a nut or bolt of regular polygonal shape, said wrench having a cavity of subsurfaces for engaging and turning said nut in either a clockwise or counterclockwise direction of rotation about the central axis of said regular polygonal shape, which subsurfaces are symmetrical with respect to said axis when engaging said nut in either direction of rotation, and at which times the engaging subsurfaces of said cavity are all essentially parallel to said axis, and where during turning there are one or more sets of such subsurfaces employed exclusively in turning said nut in the clockwise direction and one or more sets employed exclusively in turning said nut in the counterclockwise direction of rotation, each such set having at least one pair of opposing subsurfaces, and where the magnitude of the acute dihedral angle formed by the intersection of the plane of any subsurface for turning in clockwise rotation and the plane of that adjacent subsurface for turning said nut in counterclockwise rotation which engages the nut in the vicinity of the same vertex of the nut as said "any subsurface" is substantially greater than $360^\circ/n$, where n is the number of sides in said polygonal shape, and where the perpendicular distance between any two opposing said subsurfaces of said wrench in any such set falls within the range from 0.01 of nominal below (that is, less than) nominal to 0.01 of nominal above (that is, greater than) nominal, thus making the range from 0.990 of nominal to 1.010 of nominal, when the nut to be turned is made of heated-treated and hardened steel; and falls within the range from 0.01 of nominal below 0.991 of nominal to 0.01 of nominal above 0.991 of nominal, thus making the range from 0.981 of nominal to 1.001 of nominal, when the nut to be turned is made of mild steel; and falls within the range from 0.01 of nominal below 0.982 of nominal to 0.01 of nominal above 0.982 of nominal, thus making the range from 0.972 of nominal to 0.992 of nominal, when the nut to be turned is made of soft metal, such as brass or aluminum.

2. A wrench for turning a nut of regular polygonal shape, said wrench having a cavity of subsurfaces for engaging and turning said nut in either a clockwise or counterclockwise direction of rotation about the cen-

tral axis of said regular polygonal shape, which subsur-
 faces are symmetrical with respect to said axis when en-
 gaging said nut in either direction of rotation, and at
 which times the engaging subsurfaces of said cavity are
 all essentially parallel too said axis, and where during
 turning there are one or more sets of such subsurfaces
 employed exclusively in turning said nut in the clock-
 wise direction of rotation and one or more sets of such
 subsurfaces employed exclusively in turning said nut in
 the counterclockwise direction of rotation, each such
 set having at least one pair of opposing subsurfaces,
 and where the magnitude of the acute dihedral angle
 formed by the intersection of the plane of any subsur-
 face for turning in clockwise rotation and the plane of
 that adjacent subsurface for turning said nut in coun-
 terclockwise rotation which engages the nut in the vi-
 cinity of the same vertex of the nut as said "any subsur-
 face" is substantially greater than $360^\circ/n$, where n is the
 number of sides in said polygon and where the perpen-
 dicular distance between any two opposing subsurfaces
 of any set of subsurfaces employed in turning the nut
 clockwise is less than the perpendicular distance be-
 tween any two opposing subsurfaces of any set of sub-

surfaces employed in turning the nut counterclockwise.

3. A wrench for turning polygonal nuts of nominal
 size where said wrench has a gripping cavity with a cen-
 tral axis parallel to and equidistant from each of every
 set of opposing gripping surfaces in said cavity, and
 where, when said axis of said wrench coincides with the
 central axis of said polygonal nut and said wrench is
 turned about said axiss in a counterclockwise direction
 with respect to said nut until contact is made between
 said gripping surfaces and the corresponding nut faces
 the dihedral angle formed by any of said wrench grip-
 ping surfaces and the corresponding nut faces, herein
 called "the approach angle," is such that at the time
 when maximum torque is applied to the nut by the
 wrench the magnitude of this dihedral angle, because
 of strain in the nut and the wrench, is zero or greater.

4. A wrench of claim 3 where when said wrench is
 turned clockwise rather than counterclockwise the
 magnitude of said dihedral angle formed is substantially
 different from that formed when said wrench is used to
 turn said nut counterclockwise.

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