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(54) RECIRCULATORY BALL SPINDLE AND NUT

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This invention relates to a recirculatory ball spindle and nut. Such spindle and nut arrangements have a high precision pitch and balls provided between the spindle and the nut as rolling contact bodies which are accommodated in screwthread-like ball tracks of equal pitch machined into spindle and nut, transferring or returning means being provided for recirculating the balls.

As is known, recirculatory ball spindle and nut arrangements have been developed from sliding screw transmissions, in which a screwthreaded spindle and a screwthreaded nut cooperate directly with each other in mutual contact, by the arrangement of rolling contact bodies in the form of steel balls between the screwthreads of the spindle and the nut. It was then possible by this means to reduce very considerably the co-efficient of friction in the recirculatory ball spindle and nut. Furthermore, a longer useful life with simultaneously more constant precision was achieved, as well as a reduction in wear.

In the previously known recirculatory ball spindle and nut arrangements the ball tracks used are screwthreaded shapes which range from pointed shapes through trapezoidal screwthreads to the so-called Gothic shape with a definite bearing line for the balls. The Gothic profile is used preferentially in high precision recirculatory ball spindles and nuts.

However, the nature of the screwthread shape and the hardness of the ball tracks, which are constituted by grooves, are important conditions for a long useful life and for the retention more particularly of the initial precision of a recirculatory ball spindle and nut. Particularly favourable conditions are

obtained for practical purposes if a precise uniform cross-sectional shape of the ball track along the total length of the spindle is present, while the track has only the smallest possible errors of pitch, and if a uniformly high hardness of 62—64 HR_c (Rockwell) is present in the bearing screwthread flanks as well as an adequate depth of hardness to obtain rigidity.

These particularly favourable properties can, however, be achieved in high precision recirculatory ball spindles and nuts of the type previously known, by an extremely complicated production method comprising a large number of individual work stages, which will now be described.

In a first work stage it is necessary to effect a hardness test on a smooth cylindrical bar from the same stock as the actual spindle material, in order that the values of the longitudinal distortion can be determined. Then, taking into consideration the longitudinal distortion found, in a second work stage a corrected preliminary turning or preliminary whirling of the screwthread on the spindle portion is performed so as to avoid the time-wasting grinding of the screwthread into the solid material of a hardened bar with the stresses and distortions thereby released in the spindle. Then, after completing these operations, in a third work stage the spindle is subjected to a hardening process in which it is preferably flame-hardened or inductively hardened. Then, in a fourth work stage the spindle is annealed, cleaned and subjected to a check in which a fissure test is effected and the longitudinal distortions also determined. A fifth work stage then consists in straightening the spindle. After straightening, in a further sixth work stage the spindle is ground circular externally, and finally in a seventh work stage the screw threaded shape is ground, during which, if necessary, corrections due to longitudinal distortion during hardening must be effected.

In the course of such production procedure the hardening of the spindle in the third work stage in particular must be carried out with special care because the rod-

shaped body which is to be hardened no longer has uninterruptedly continuous cylindrical configuration, on the contrary screw-threaded shapes having a different screw-thread depth and pitch compared to the individual diameters of the spindles are present. There is therefore a risk of differences of hardness in the thread flanks, which lead to stress fissures. For this reason the final work stage in which the screwthreaded shape is ground then also presents particular difficulties if the hardness and the depth of hardness are not uniform so that uncontrollable stresses may appear during final grinding. The result of this is that deviations as regards the precision of pitch occur so that the circularity of the spindle is impaired. Even straightening operations carried out subsequently cannot eliminate these disadvantages, on the contrary fresh stresses then occur.

To summarise, it must be stated that in the case of the previously known recirculatory ball spindle and nut arrangements, due to the comparatively deeply dimensioned ball track a comparatively high proportion of cutting work must be carried out during the course of production and that comparatively great depths of hardness must also be possible in order to achieve the requisite strength. Furthermore, in the context of precision production an unavoidable rejection rate is experienced because each individual operation has to be carried out with extreme care if an optimum construction is to be achieved, but this naturally presents considerable difficulties.

It is therefore the aim of the invention to provide a recirculatory ball spindle and nut arrangement which, particularly whilst having a compact construction, constitutes a high precision arrangement which can be produced with considerably reduced production outlay and furthermore with fewer problems.

Accordingly, the present invention consists in a recirculatory ball spindle and nut, wherein the ratio of maximum ball track depth to the diameter of the balls is substantially within the range 1:4 to 1:7, and wherein the cylindrical surfaces of the spindle and nut, before the grooves are cut, have a radial depth of hardening which is greater than the maximum depth of the ball track. The present invention also consists in a method of producing a recirculatory ball spindle and nut, which comprises first hardening the outer peripheral surface of the spindle stock and the inner peripheral surface of the nut stock and subsequently machining by grinding in said surfaces helical grooves which constitute the ball tracks; the ratio of maximum groove depth to the diameter of the balls to be used being substantially within the range 1:4 to 1:7 and

the radial depth of hardening being greater than the maximum depth of the groove.

Thus the application to recirculatory ball spindle and nut arrangements of the teaching known from axial thrust ball-bearings has the effect that their production can be simplified because the otherwise inevitable operations in the production of heretofore known high precision recirculatory ball spindle and nut arrangements, which relate to the trial hardening, to the determination of the longitudinal distortion and to the preliminary turning or preliminary whirling of the screw-threaded ball tracks on the spindle, and which relate to the first and second operations of the known manufacturing procedure, can be omitted. On the contrary, in the case of the arrangement of the invention the shape of the ball tracks can be ground with the desired pitch direct into the hardened smooth peripheral surface both of the spindle and of the nut, so that by this possibility in spite of maintaining the desired precision a not inconsiderable simplification is achieved. A further advantage which results in connection with the direct grinding of the ball track shape into the hardened surface, is that now even the work outlays unavoidable in the case of previously known recirculatory ball spindle and nut arrangements, for the longitudinal distortion control, for the cleaning of the hardened and annealed preliminary turned spindle, and even the corrected grinding of the screw-thread shape, which relate to the previously known final operation, can be omitted.

According to an optional feature of the invention the depth of hardening of the spindle and nut is at least equal to or greater than the diameter of the balls and is not less than HR_c (Rockwell) 65—64 at the surface. With such construction it is ensured that the core zone retains the necessary toughness. When the stated hardness values are present, optimum conditions are achieved for the object of the invention.

Another advantage also lies in the fact that the development of released stresses during the grinding of the ball tracks is eliminated owing to the constant depth of hardness which is greater compared to the maximum ball track depth. The precision of pitch which is attainable is therefore only a function of the precision of the grinding machine and it is thus possible to grind spindle pairs of equal precision without particular outlay.

Furthermore, the transfer of the known tolerances in the production of precision grooved thrust ball-bearings to the grinding of the present ball grooves or tracks produces a minimum radial loading of the ball tracks and of the balls which is still further considerably reduced because in contrast to plane groove ball-bearings, the balls can roll

within the pitch. This likewise contributes to favouring the useful life of such arrangements. The maximum ball groove depth in spindle and nut may be 0.7 mm, that is for a ball diameter 4.762 mm and a pitch of 6 mm. Due to this relatively shallow depth of penetration of the ball grooves into the material both of the spindle and also of the nut, a considerably greater free space is obtained between the spindle outer and the nut inner peripheral surfaces than in the case of recirculatory ball spindle and nut arrangements of the previously known type, so that this space can advantageously be utilised as a grease chamber for permanent lubrication. This grease chamber then constitutes a unit sealed from the exterior by grease proof seals and wipers, while owing to the shallow depth of penetration of the ball grooves no difficulties for satisfactory and durable sealing occur on the spindle. It has been found that a moment of friction virtually independent of load then occurs between spindle and nut if the grease chamber is packed with a lubricant of suitable quantity and viscosity.

However, the object of the invention relates not only to the transfer of the teaching of axial thrust ball-bearings to a recirculatory ball spindle and nut system, and a particularly favourable arrangement is obtained if the ball groove depth in the nut, in conformity with its higher degree of wear, exceeds the depth of the ball grooves in the spindle, the whole conveniently so that, for example the ball groove depth in the spindle is dimensioned in a ratio approximately 1:5 to the diameter of the balls, whereas the ball groove depth in the nut is dimensioned in a ratio approximately 1:4.5 to the diameter of the balls.

With an arrangement as above proposed, having regard to the higher ball circulation rates in the nut moved by the normally much longer spindle and hence subject to higher loading, the practical desiderata are fulfilled in a particularly satisfactory manner, which also has repercussions on the overall rigidity of the spindle and nut system. Also, due to the ball grooves lying deeper in the nut compared to the spindle, a particularly large area of contact is obtained for the balls, so that a weaker specific pressure and a reduction of wear with higher load capacity is achieved.

However, in addition to the simplification of production of spindle and nut arrangement achieved by the invention, still other advantages are achieved from the standpoint of a particularly utilitarian construction, inasmuch as more particularly the nut may be conformed only so thin as regards its wall thickness that the necessary rigidity of the spindle and nut system is obtained. This wall thickness should conveniently be chosen so

that any elastic deformation caused by radial forces of the balls can be kept as slight as is possible. Thus a relatively light nut can be effectively utilised for the higher demands.

In order that the invention may be more readily understood, reference is made to the accompanying drawings which illustrate diagrammatically and by way of example one embodiment thereof, and in which:—

Fig. 1 shows a re-circulatory ball spindle and nut arrangement in longitudinal section, and

Fig. 2 is an enlarged view of the detail "x" of Fig. 1.

In a hardened spindle 1, guide grooves 2 for balls 3 are ground helicoidally into the circumference of the spindle. Likewise, in a hardened nut 5 grooves 4 are ground in the same way so that the grooves 2 of the spindle 1 and the grooves 4 of the nut 5 have equal pitch. The balls 3 roll between the grooves 2 of the spindle 1 and the grooves 4 of the nut 5. Between the spindle 1 and the nut 5 there is provided an annular space 6 which can be utilised as a grease chamber and which is sealed axially from the outside by grease proof seals (not shown) and wipers 7 attached to the nut.

In the present embodiment, the depth of rugosity of the grooves 2 and 4 is required to be equal to or less than $1\text{ }\mu\text{m}$. Furthermore the grooves 2 and 4 are required to have hardness values not less than 62 to 64 HR_c (Rockwell) along their entire extent into the groove edges 2a and 4a. This requirement is not difficult to fulfil in the case of ball-bearing steels. Furthermore the depth of hardness in the spindle 1 and nut 5 should be at least equal to or greater than the diameter of the balls 3 in order to attain high rigidity in the spindle and nut system.

The ratio of the depth of the grooves 2 and 4 to the diameter of the balls 3 is particularly clearly visible in the enlarged detail view of Fig. 2. In the spindle 1 according to the present embodiment, if the maximum depth of the groove 2 is 0.6 mm, and the ball has a diameter of 3.175 mm, then a ratio of approximately 1:5 is obtained. In contrast to this, the maximum depth of the groove 4 in the nut 5 is stated as approximately 0.7 mm, so that a greater depth prevails here. The depth of 0.7 mm, when set as ratio to the ball diameter, gives a value of approximately 1:4.5. If the spindle has a comparatively great length, then the depth may also be greater, for example 0.8 mm, that is in conformity with a ratio of 1:4.

In all cases of the chosen groove depth, the osculation factor should be chosen in conformity with the teaching of axial thrust ball-bearings.

By virtue of the arrangement described in the present embodiment, particularly favourable conditions are obtained in practice as

regards the overall arrangement, so that the described construction constitutes a particularly practical arrangement. It should also be mentioned in this connection that means (not shown) to ensure an undisturbed circulation of balls in the nut 5 are also provided, which permit a transfer and/or return of the balls, for example known individual transfer insert pieces could be used here, or other means which effect a frictionless recirculation of the balls.

Furthermore, due to the comparatively shallow depth of the ball grooves the difficulties of the ball return across the screwthread flanks of a known recirculatory ball screwthreaded spindle are virtually eliminated in the proposed spindle. And lastly it is likewise possible to maintain the balls in the screwthread pitch by means of ball cages. There is also the possibility to make an axial residual play adjustable in known manner by prestressed double nuts, and thus also to support the overall rigidity of the spindle and nut assembly. The cross-sectional shape of the ball tracks in the spindle and nut may, at least in part, be defined by two parabolas or two arcs of a circle.

WHAT WE CLAIM IS:—

1. A recirculatory ball spindle and nut, wherein the ratio of maximum ball track depth to the diameter of the balls is substantially within the range 1:4 to 1:7, and wherein the cylindrical surfaces of the spindle and nut, before the grooves are cut, have a radial depth of hardening which is greater than the maximum depth of the ball track.

2. A recirculatory ball spindle and nut as claimed in claim 1, wherein the geometrical cross-sectional form of the ball tracks corresponds to that of the ball tracks of axial thrust ball bearings.

3. A recirculatory ball spindle and nut as claimed in claim 1 or 2, wherein the cross-sectional shape of the ball tracks in the spindle and nut is defined, at least in part, by two parabolas or two arcs of a circle.

4. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the depth of the hardening of the

spindle and nut is at least equal to or greater than the diameter of the balls.

5. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the maximum depth of the ball tracks in the nut is greater than that in the spindle.

6. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein an annular space is provided between the spindle and the nut, which space is filled with a durable lubricating medium and is sealed off at both ends by means of grease proof seals and wipers attached to the nut.

7. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the hardness has a value of not less than 62 to 64 HR. (Rockwell).

8. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the depth of rugosity of the ball tracks is equal to or less than 1 μ m.

9. A recirculatory ball spindle and nut, substantially as herein described with reference to and as shown in the accompanying drawings.

10. A method of producing a recirculatory ball spindle and nut, which comprise first hardening the outer peripheral surface of the spindle stock and the inner peripheral surface of the nut stock and subsequently machining by grinding in said surfaces helical grooves which constitute the ball tracks, the ratio of maximum groove depth to the diameter of the balls to be used being substantially within the range 1:4 to 1:7 and the radial depth of hardening being greater than the maximum depth of the groove.

11. A method of producing a recirculatory ball spindle and nut, substantially as herein described with reference to and as shown in the accompanying drawings.

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Furthermore, due to the comparatively shallow depth of the ball grooves the difficulties of the ball return across the screwthread flanks of a known recirculatory ball screwthreaded spindle are virtually eliminated in the proposed spindle. And lastly it is likewise possible to maintain the balls in the screwthread pitch by means of ball cages. There is also the possibility to make an axial residual play adjustable in known manner by prestressed double nuts, and thus also to support the overall rigidity of the spindle and nut assembly. The cross-sectional shape of the ball tracks in the spindle and nut may, at least in part, be defined by two parabolas or two arcs of a circle.

WHAT WE CLAIM IS:—

1. A recirculatory ball spindle and nut, wherein the ratio of maximum ball track depth to the diameter of the balls is substantially within the range 1:4 to 1:7, and wherein the cylindrical surfaces of the spindle and nut, before the grooves are cut, have a radial depth of hardening which is greater than the maximum depth of the ball track.

2. A recirculatory ball spindle and nut as claimed in claim 1, wherein the geometrical cross-sectional form of the ball tracks corresponds to that of the ball tracks of axial thrust ball bearings.

3. A recirculatory ball spindle and nut as claimed in claim 1 or 2, wherein the cross-sectional shape of the ball tracks in the spindle and nut is defined, at least in part, by two parabolas or two arcs of a circle.

4. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the depth of the hardening of the

spindle and nut is at least equal to or greater than the diameter of the balls.

5. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the maximum depth of the ball tracks in the nut is greater than that in the spindle.

6. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein an annular space is provided between the spindle and the nut, which space is filled with a durable lubricating medium and is sealed off at both ends by means of grease proof seals and wipers attached to the nut.

7. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the hardness has a value of not less than 62 to 64 HR, (Rockwell).

8. A recirculatory ball spindle and nut as claimed in any of the preceding claims, wherein the depth of rugosity of the ball tracks is equal to or less than 1 μ m.

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