

PATENT SPECIFICATION

(11) 1 462 244

1 462 244

(21) Application No. 11846/74 (22) Filed 18 March 1974

(31) Convention Application No. 2317617

(32) Filed 7 April 1973 in

(33) Germany (DT)

(44) Complete Specification published 19 Jan. 1977

(51) INT CL² B29F 3/06 B29B 1/10

(52) Index at acceptance

B5A 1G3X 1G5A 1G5E

B1C 19G4A1 1



(54) MULTI-WORM EXTRUDER

(71) We, ~~KRAUSS MAFFEI AKTIENGESELLSCHAFT~~, A German Body Corporate, of 2, Krauss-Maffei Strasse, Munchen, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a multi-worm extruder for thermoplastic synthetic plastics materials, having a central screw or worm and a number of smaller auxiliary screws or worms arranged in meshing engagement and axially parallel with the central worm. The auxiliary worms are uniformly distributed about the periphery of the central worm and are driven with a fixed transmission ratio relative to the central worm.

Extruders are already known which work according to the contra-rotating double worm system. Such extruders have as plasticising unit a cylinder having two parallel mutually intersecting bores of circular cross-section in which conveying or plasticising worms run at equal rotation speeds, driven in opposite directions. In relation to the worm channels of each worm, the worm threads of the other worm form intermeshing ridges so that the conveyed material is enclosed in several separate C-shaped chambers. The chambers of each worm are in communication with one another and with the chambers of the second worm through the roll gap and flank gap. The roll gap, that is the gap between the thread outer surface of the one worm and the core of the other worm, is determined by the worm external diameter, core diameter and axial spacing of the worms. The flank gap, that is the gap between the thread flanks which rotate past one another, is determined by the worm geometry.

It is further known for several worms to mesh with one common central worm. It is here regarded as especially advantageous if the positively driven auxiliary worms are

arranged axially parallel in uniform distribution over the periphery of the central worm. The contra-rotating worms in meeting form a cusp in which the thermoplastic material is subjected to shear action, squeezed and kneaded.

The advantage of the multi-worm extruder over the double-worm extruder consists in that in large machines it is not necessary to have worms with a relatively large diameter, but that with an increase in size of the extruder only the central worm is increased in diameter and the number of auxiliary worms rises, so that with the number of the auxiliary worms the number of cusps between the central and auxiliary worms also increases and the volume of the chambers remains approximately equal, so that the heat-sensitive synthetic plastics material, which is usually a poor thermal conductor, is melted uniformly with small heat graduations.

In such a multi-worm extruder the mean channel diameter of the auxiliary worms is equal to the mean channel diameter of the central worm divided by the number of auxiliary worms. In this case the number of channels (each defined by one circumferential turn) and their pitch must be in the reverse ratio to the rotational speeds, namely with equal channel dimensions. Thus a more or less rigid ratio of sizes of the worms to one another is achieved.

The present invention may render possible the uniform plasticising and delivery of the thermoplastic synthetic plastics material in the central worm and in the auxiliary worms.

According to the invention, there is provided a multi-screw extruder for thermoplastic materials, comprising a central worm and a number of auxiliary worms which have a smaller outer diameter relative to the diameter of the central worm, which are in meshing engagement with and axially parallel to the central worm, which are evenly distributed about the circumference of the central worm and

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which are each positively drivable in the opposite direction to the direction of rotation of the central worm; the ratio of the pitch of each auxiliary worm relative to the pitch of the central worm being the inverse of the number of auxiliary worms; the rotational speed of each auxiliary worm relative to the rotational speed of the central worm being proportional to the number of auxiliary worms; the number of threads of each auxiliary worm being proportional to the number of threads of the central worm in the ratio of the respective pitches; wherein the outer diameter of the central worm is equal to the outer diameter of the auxiliary worms multiplied by the number of auxiliary worms and wherein the ratio of the cross sectional areas of the channels of the central worm to the cross sectional areas of the channels of each auxiliary worm is the inverse of the ratio of the circumferential lengths, as hereinbefore defined, of the respective channels.

It follows automatically from this construction that the relative rotational speeds of the auxiliary worms relative to the central worm is such that the outer circumferential speed of the central worm is equal to the outer circumferential speed of each auxiliary worm.

Preferably, the cross sectional area of a first gap consisting of a first flank gap between the core surface of an auxiliary worm and the mean circle diameter line (as hereinafter defined) and further consisting of a first roll gap between the core surface of the auxiliary worm and the outer thread surface of the central worm, is larger than the cross sectional area of a second gap consisting of a second flank gap between the core surface of the central worm and the mean circle diameter line and further consisting of a second roll gap between the core surface of the central worm and the outer thread surface of the auxiliary worm. The "mean circle diameter line" is defined as the average of the mean diameter (i.e. half flank height) of the central worm and the mean diameter (i.e. half flank height) of the associated auxiliary worm.

In one embodiment of the invention the widths of the channels of the central worm and of the auxiliary worm are made of different magnitudes, the shape of the channels of the central worm and of the auxiliary worms are made different, and the roll gaps of the central worm and of the auxiliary worm are made of different sizes.

Furthermore, the ratio of the channel widths; that is between thread flanks, of the auxiliary worms and of the central worm is substantially in the reverse ratio of the respective radial channel surface areas. The width of the channels of the central worm

can be up to about 20% smaller than that of the auxiliary worms. One roll gap, between the core diameter of the auxiliary worm and the external diameter of the central worm, may be larger by up to about 50% than the gap between the core surfaces of the auxiliary worms and the outer thread surfaces of the central worm. Moreover, the axial dimension of the first flank gap may be larger than the axial dimension of the second flank gap. By circumferential length is meant the length of that portion of each circumferential turn which is not in engagement with the other of the central or auxiliary worms. In the case of the central worm the channel length is the length between adjacent auxiliary worms. This length is measured at the middle of the flight height.

With the multi-worm extruder according to the invention in the processing of thermoplastic synthetic plastics material with different viscosities and different flow behaviours, a most precise ratio of the dissipation of thermal energy to the quantity of material fed out of the extruder is achieved, which in the ideal condition must be equal in the central worm and in the auxiliary worms. A substantial approximation to this ratio is provided by the fact that the volumes of material moved in the axial direction per unit of time are of substantially equal magnitude in the channels of one auxiliary worm in each case within and outside its meshing region (cusp) with the central worm and in the channels of the central worm in the above-mentioned meshing region thereof and between the auxiliary worms.

Heating of plastics material caused by friction between the auxiliary worms and their cylinders can be substantially reduced by adjusting for lateral pressure between the auxiliary and central worms. The heat losses in the plastics material must then be compensated for to maintain thermal balance by increasing the milling work on the plastics material. This can be achieved by a reduction of the axial material forward thrust in the central worm and by increasing the axial material forward thrust in the auxiliary worms. The volume of the central worm and of the auxiliary worm will most easily be made equal to one another with a variation of thread and channel width.

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawing, wherein:—

Figure 1 shows the cross-section of a multi-worm extruder for the production of tubes,

Figure 2 shows the multi-worm extruder according to Figure 1 in longitudinal

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central section, with a stationary mandrel fixedly mounted in a central hollow region of the central worm, which mandrel together with a nozzle passage forms a final extruding die for the production of tubes,

Figure 3 is a partial view of the multi-worm extruder according to Figures 1 and 2 on a larger scale;

Figures 4 and 5 show flank and roll gaps between non-tightly meshing worms of equal and unequal channel widths in the region of the engagement of an auxiliary worm with the channels of the central worm according to Figures 1 and 2, likewise on a larger scale, the mean circle diameter line being illustrated as straight dot-and-dash lines; and

Figure 6 shows an enlarged representation, transferred into the plane of the drawing, of a channel of an auxiliary worm within and outside its cusp with the central worm and the part of a channel of the central worm working upon this auxiliary worm, within and outside the same meshing zone.

The multi-worm extruder (Figures 1 to 6) consists of a central worm 1 and four auxiliary worms 2. Each auxiliary worm is arranged offset by 90° from the next. Each channel 14 (hatched in Figure 6) of each auxiliary worm 2 here lies in each case within and outside an engagement cusp 4 with the central worm.

A channel 15 (hatched in Figure 6) of the central worm 1 also engages in each such engagement cusp.

The conveyed material which is situated in the channels 14, 15 is partially drawn through a gap formed in each case between the central worm 1 and an auxiliary worm 2 and partially pushed forward and expelled in the axial direction. The ratio of a part of the conveyed material which is pushed forward or expelled on one revolution of an auxiliary worm 2, to the entire conveyed material situated in one auxiliary worm channel, defines the conveying efficiency. The heating of the thermoplastic synthetic plastics material increases uniformly in the case of equal volumes and conveying efficiencies of the channels in the central worm and in the auxiliary worms, if the energy conversion caused by shear action, friction and through-flow is likewise equal.

The conveyed materials of the channels 14 and 15 (Figures 4, 5, 6) meet at the mean abutment line of roll and flank gaps 8 and 9. Good material and pressure equalisation is achieved when the average position of these gaps coincides with the mean circle diameter line 7 (Figures 4, 5). This coincidence is achieved by an appropriate selection of the sizes of the roll and flank gaps 8 and 9 (Figure 4).

In Figure 4 the gap 8 lying on one side of

the mean circle diameter line 7 defines the passage (part of the channel 14) for the conveyed material of an auxiliary worm 2 within a meshing engagement region (cusp 4) between the central worm and an auxiliary worm. On the other hand the gap 9 lying on the other side of the mean circle diameter line 7 designates the passage (part of the channel 15) for the conveyed material of the central worm 1 within the same meshing engagement region (cusp 4).

The variation of flow volumes and resistance to flow of material can be achieved by the variation of the volumes of the channels and/or of the gaps 8 and 9 of central worm 1 and auxiliary worms 2. Such variation is achieved by physically changing the worms. Each volume is determined in every worm (central and auxiliary worms 1, 2) by the diameter, the channel depth, the pitch and the distribution of worm thread and channel widths, and therefore can be increased or reduced at least in the new manufacture of a multi-worm extruder.

The flow resistance of material can be varied for example in the engagement cusp of auxiliary and central worms 1 by increasing (Figures 4 and 5) the flank gap between the thread flanks as shown at 10, 100 and/or increasing roll gaps 13, 130, that is the gaps 8, 9 in the region of the cusps 4, while maintaining the volumes of the channels the same. These variations can be effected in the case of central and auxiliary worms 1, 2 as shown in Figure 4 with channels 14, 15 of equal widths and in the case of central and auxiliary worms 1, 2 as shown in Figure 5 with channels 14, 15 of unequal widths 16, 17 respectively. An increased portion 100 of the flank gap 10 alone or together with an increased portion 130 of the roll gap 13 results in a larger radial material circulation. The portion 100 of the flank gap 10 on the auxiliary worm alone, leaving the usual channel depth, that is without variation of the roll gap 13, has a twofold effect because it effects a reduction of the conveying efficiency of the central worm 1 and an increase of the movement of material in the respective auxiliary worm. A corresponding variation of the conveying efficiency of auxiliary worm 2 and central worm 1 can be achieved if the roll gap 13 of the central worm 1 or of the auxiliary worms 2 is provided with the increased portion 130. In a modification of the form of the increased portion 100 of the flank gap as shown in Figures 4 and 5, this portion can for example also receive the form of a bevelling starting from the region of the mean circle diameter line 7, making the outer width of the thread narrower.

Singly, or in combination with, the provision of portions 100, 130 of the flank and roll gaps 10, 13, very effective and

5 favourable variations of the conveying efficiencies of the central worm and of the auxiliary worms and of the material passage volumes of central worm and auxiliary worms in relation to the central worm 1 and in relation to the auxiliary worms 2 can also be achieved by the formation of wider threads 12 (Figure 5) of the central worm 1 and at the same time narrower threads 11 of the auxiliary worms 2, while maintaining equal channel volumes.

10 In the case of central and auxiliary worms formed in such a manner with threads and channels of different widths, the ratio of the channel widths of the auxiliary worms and of the central worm is inversely proportional to the ratio of their respective radial channel surface areas. The width of the channels of the central worm can here be up to about 20% smaller than that of the auxiliary worms.

WHAT WE CLAIM IS:—

1. A multi-screw extruder for thermoplastic materials, comprising a central worm and a number of auxiliary worms which have a smaller outer diameter relative to the diameter of the central worm, which are in meshing engagement with and axially parallel to the central worm, which are evenly distributed about the circumference of the central worm and which are each positively drivable in the opposite direction to the direction of rotation of the central worm; the ratio of the pitch of each auxiliary worm relative to the pitch of the central worm being the inverse of the number of auxiliary worms; the rotational speed of each auxiliary worm relative to the rotational speed of the central worm being proportional to the number of auxiliary worms; the number of threads of each auxiliary worm being proportional to the number of threads of the central worm in the ratio of the respective pitches; wherein the outer

diameter of the central worm is equal to the outer diameter of the auxiliary worms multiplied by the number of auxiliary worms, and wherein the ratio of the cross sectional areas of the channels of the central worm to the cross sectional areas of the channels of each auxiliary worm is the inverse of the ratio of the circumferential lengths, as hereinbefore defined, of the respective channels.

2. An extruder as claimed in Claim 1, wherein the cross sectional area of a first gap consisting of a first flank gap between the core surface of an auxiliary worm and the mean circle diameter line (as hereinbefore defined) and further consisting of a first roll gap between the core surface of the auxiliary worm and the outer thread surface of the central worm, is larger than the cross sectional area of a second gap consisting of a second flank gap between the core surface of the central worm and the mean circle diameter line and further consisting of a second roll gap between the core surface of the central worm and the outer thread surface of the auxiliary worm.

3. An extruder as claimed in Claim 2, wherein the radial dimension of the first roll gap is larger by up to 50% than the radial dimension of the second roll gap.

4. An extruder as claimed in Claim 2 or 3, wherein the axial dimensions of the first flank gap is larger than the axial dimension of the second flank gap.

5. A multi-screw extruder substantially as hereinbefore described with reference to the accompanying drawings.

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5 favourable variations of the conveying
efficiencies of the central worm and of the
auxiliary worms and of the material passage
volumes of central worm and auxiliary
worms in relation to the central worm 1 and
in relation to the auxiliary worms 2 can also
be achieved by the formation of wider
threads 12 (Figure 5) of the central worm 1
and at the same time narrower threads 11 of
the auxiliary worms 2, while maintaining
equal channel volumes.

10 In the case of central and auxiliary
worms formed in such a manner with
threads and channels of different widths,
the ratio of the channel widths of the
auxiliary worms and of the central worm is
inversely proportional to the ratio of their
respective radial channel surface areas. The
width of the channels of the central worm
can here be up to about 20% smaller than
that of the auxiliary worms.

WHAT WE CLAIM IS:—

1. A multi-screw extruder for
thermoplastic materials, comprising a
central worm and a number of auxiliary
worms which have a smaller outer diameter
relative to the diameter of the central
worm, which are in meshing engagement
with and axially parallel to the central
worm, which are evenly distributed about
the circumference of the central worm and
which are each positively drivable in the
opposite direction to the direction of
rotation of the central worm; the ratio of
the pitch of each auxiliary worm relative to
the pitch of the central worm being the
inverse of the number of auxiliary worms;
the rotational speed of each auxiliary worm
relative to the rotational speed of the
central worm being proportional to the
number of auxiliary worms; the number of
threads of each auxiliary worm being
proportional to the number of threads of
the central worm in the ratio of the
respective pitches; wherein the outer

diameter of the central worm is equal to the
outer diameter of the auxiliary worms
multiplied by the number of auxiliary
worms, and wherein the ratio of the cross
sectional areas of the channels of the
central worm to the cross sectional areas of
the channels of each auxiliary worm is the
inverse of the ratio of the circumferential
lengths, as hereinbefore defined, of the
respective channels.

2. An extruder as claimed in Claim 1,
wherein the cross sectional area of a first
gap consisting of a first flank gap between
the core surface of an auxiliary worm and
the mean circle diameter line (as
hereinbefore defined) and further
consisting of a first roll gap between the
core surface of the auxiliary worm and the
outer thread surface of the central worm, is
larger than the cross sectional area of a
second gap consisting of a second flank gap
between the core surface of the central
worm and the mean circle diameter line
and further consisting of a second roll gap
between the core surface of the central
worm and the outer thread surface of the
auxiliary worm.

3. An extruder as claimed in Claim 2,
wherein the radial dimension of the first roll
gap is larger by up to 50% than the radial
dimension of the second roll gap.

4. An extruder as claimed in Claim 2 or 3,
wherein the axial dimensions of the first
flank gap is larger than the axial dimension
of the second flank gap.

5. A multi-screw extruder substantially as
hereinbefore described with reference to
the accompanying drawings.

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