

TITLE OF THE INVENTION: A FLEXSPLINE, A HARMONIC GEAR AND A METHOD OF PREPARATION

FIELD OF THE INVENTION

5 [0001] The present invention relates to a flexspline and a method of preparing the flexspline with a moulding apparatus. The flexspline may be used in a harmonic gear.

BACKGROUND OF THE INVENTION

[0002] A harmonic gear (also known as a strain wave gear) provides high gear
10 reduction ratios in a small volume and may be also called a harmonic reducer. Harmonic gears are widely used in the joints of robotic arms of robot due to their high transmission efficiency, high action accuracy, and large reduction ratios.

[0003] A harmonic gear is generally made up of three components including an outer spline which is rigid and with a set of internal gear teeth, a flexspline with a set of external
15 facing gear teeth, and a wave generator. The flexspline (may also be spelled flex spline and known as a soft wheel) is fitted inside the outer spline and the teeth of the flexspline engages with the teeth of the outer spline such that the motion of one set of teeth causes the motion of the other corresponding set of teeth and thus allows for the harmonic gear to function. A key feature of the harmonic gear is that the flexspline has fewer gear teeth than
20 the outer spline. The wave generator is made up of two parts – an elliptical disk and a ball bearing. The flexspline is fitted over the wave generator and deforms to an elliptical shape with a major longitudinal axis such that only the teeth of the flexspline located at the ends of the major longitudinal axis engages with the teeth of the outer spline. Assuming the wave generator is the input rotation, as the wave generator rotates and presses against the
25 flexspline and the flexspline rotates in the opposite direction of the wave generator. The major longitudinal axis of the flexspline thus moves (or rotates) and the teeth of the flexspline engages the teeth of the outer spline in a rotational motion and correspondingly rotates the outer spline.

[0004] In the process of using the harmonic gear, the flexspline needs to withstand
30 periodic deformation to transmit torque. The main parameters that restrict the application of harmonic reducers include the lifespan of the flexspline and the max torque value it can

withstand, which are contradictory to each other. The main defects of existing flexspline are that it is prone to fatigue failure due to the periodic deformation and alternating stress on the flexspline during its use in the harmonic gear and a large amount of heat generated during the deformation process due to poor heat dissipation conditions. As such there is a need for a flexspline that can withstand extended usage and deformation but is still able to withstand high torque values.

SUMMARY OF THE INVENTION

[0005] In various embodiments described herein, there is described a flexspline with a composite structure, and a manufacturing process of the flexspline, which can significantly improve the load that can be withstand and fatigue life of the flexspline and consequently its use in the harmonic reducer.

[0006] In a first aspect, there is provided a flexspline comprising at least one sheet of carbon fibre; a plurality of gear teeth arranged along and attached to a surface of the at least one sheet of carbon fibre; and an adhesive resin to attach the at least one sheet of carbon fibre to the plurality of gear teeth, each gear tooth in the plurality of gear teeth comprises carbon fibre filaments and the adhesive resin. Preferably, each gear tooth in the plurality of gear teeth consists essentially of or consist of carbon fibre filaments and the adhesive resin. Advantageously, this provides a flexspline which has the necessary strength to withstand the periodic deformation and alternating stresses when used in a harmonic gear to provide a higher lifespan than existing flexsplines. Further, the carbon fibre sheet and carbon fibre filaments have good heat dissipation properties and avoids the buildup of heat in the flexspline.

[0007] Preferably, the flexspline further comprises a metal support, a second surface of the at least one sheet of carbon fibre is attached to the metal support with the adhesive resin, the second surface is opposite to the surface attached with the plurality of gear teeth. The second surface of the at least one sheet of carbon fibre may be attached to and cover a substantial part (i.e. all or a large part) of an exterior surface of the metal support. The interior of the metal support accommodates a shaft in the harmonic gear. More preferably, the metal support comprises a cylindrical structure with a first region attached to the plurality of gear teeth via the at least one sheet of carbon fibre and a second opposite

region or a frustoconical structure with a first region attached to the plurality of gear teeth via the at least one sheet of carbon fibre and a second opposite region, preferably the second opposite region of the cylindrical structure and the second opposite region of the frustoconical structure is thicker than the respective first region.

5 [0008] Preferably, the flexspline further comprises a metal flange attached to the second opposite region of the cylindrical structure or the second opposite region of the frustoconical structure. More preferably, the metal flange comprises a shaft channel to allow attachment to a shaft and one or more flange channels. The shaft channel allows the shaft to be accommodated within the interior of the flexspline in the harmonic gear.

10 [0009] Preferably, the carbon fibre filaments have a length from 0.2 millimetre to 10 millimetres, preferably the carbon fibre filaments are asphalt-based carbon fibre filaments.

[0010] Preferably, the plurality of gear teeth is arranged spaced part along the surface of the at least one sheet of carbon fibre such that a space between adjacent gear teeth is substantially free of carbon fibre filaments, preferably the plurality of gear teeth is
15 arranged equally spaced apart along the surface of the at least one sheet of carbon fibre. Advantageously, this allows the gear teeth to have the necessary strength whilst the flexible body is able to flex and deform the flexspline when in use in a harmonic gear.

[0011] Preferably, the at least one sheet of carbon fibre is attached to the plurality of gear teeth at an angle of about 45°.

20 [0012] Preferably, the adhesive resin comprises a first adhesive resin and a second adhesive resin, the first adhesive resin is substantially applied on the at least one sheet of carbon fibre, the second adhesive resin substantially bonds the carbon fibre filaments in each gear tooth. If multiple sheets of carbon fibre are used, the first adhesive resin attaches them together. If the metal support is present, the first adhesive resin attaches the at least
25 one sheet of carbon fibre to the metal support. The first adhesive resin and second adhesive resin attaches each other to firmly attach and join the at least one sheet of carbon fibre and the plurality of gear teeth. As the first adhesive resin and the second adhesive resin are injected as liquids at the at least one sheet of carbon fibre and gear teeth respectively when forming the flexspline, as both adhesive resins are likely to be liquids, there may be a
30 crossover or mixture of the adhesive resins. However, the at least one sheet of carbon fibre

and the gear teeth should still contain substantially the first adhesive resin and the second adhesive resin respectively.

[0013] Preferably, the adhesive resin is a thermosetting resin or a thermoplastic resin. Preferably, the adhesive resin has a temperature resistance of 300 °C and above.

5 [0014] In an embodiment, the adhesive resin is selected from the group consisting of an epoxy resin, a polyether ether ketone (PEEK) resin, silicone (may be known as polysiloxane), and any combinations thereof.

[0015] Preferably, the adhesive resin, the at least one sheet of carbon fibre and the carbon fibre filaments form a composite material. Advantageously, this forms a flexspline
10 that has the required strength but is still flexible to be used in a harmonic gear.

[0016] Preferably, a plurality of sheets of carbon fibres are layered together. Advantageously, this allows the thickness of the flexspline to be varied to fit the requirements of the flexspline and the harmonic gear.

[0017] In a second aspect, there is provided a method of preparing a flexspline, the method
15 comprising placing at least one sheet of carbon fibre between an inner mould and an outer mould; placing carbon fibre filaments in a plurality of gear tooth cavities formed between the inner mould and the outer mould; injecting an adhesive resin to bond the at least one sheet of carbon fibre and carbon fibre filaments placed between the inner mould and the outer mould; and compressing the sheet of carbon fibre, the carbon fibre filaments and the
20 adhesive resin with a compression mould.

[0018] Preferably, the method further comprises applying a vacuum during injecting the adhesive resin and/or compressing the at least one sheet of carbon fibre, the carbon fibre filaments, and the adhesive resin with the compression mould.

[0019] Preferably, injecting the adhesive resin comprises injecting a first adhesive resin
25 to the at least one sheet of carbon fibre and injecting a second adhesive resin to the carbon fibre filaments in the plurality of gear tooth cavities.

[0020] Preferably, the method further comprises placing a metal support on the inner mould and the sheet of carbon fibre on the metal support.

[0021] Preferably, the method further comprises placing a metal flange in a groove of
30 the outer mould, wherein the metal support is arranged to be attached to the plurality of gear teeth via the at least one sheet of carbon fibre at a first region and the metal support is

arranged to be attached at a second opposite region to the metal flange; and placing a filter at an end of each of the gear tooth cavities to allow gas and excess adhesive resin to flow out.

[0022] In a third aspect, there is provided a harmonic gear comprising a rigid spline having a second plurality of gear teeth; the flexspline according to any one of claims 1 to 13; and a wave generator that engages the flexspline such that a movement of the wave generator moves the flexspline and vice versa, wherein the plurality of gear teeth of the flexspline engages with the second plurality of gear teeth of the rigid spline such that a movement of the flexspline moves the rigid spline and vice versa, wherein the plurality of gear teeth of the flexspline is less than the second plurality of gear teeth of the rigid spline.

[0023] In a fourth aspect, there is provided a moulding apparatus to prepare a flexspline, the moulding apparatus comprising an inner mould, an outer mould, a compression mould, and an resin injection inlet, wherein the inner mould and outer mould are configured to be placed together to form a space to receive at least one sheet of carbon fibre and a plurality of gear tooth cavities to receive carbon fibre filaments, the compression mould is configured to be inserted into the plurality of gear tooth cavities, and the resin injection inlet is in fluid communication with the space and the plurality of gear tooth cavities.

[0024] The various aspects and embodiments described above advantageously provide a flexible that has the required strength and flexibility to be used in a harmonic gear but is also durable with a higher lifespan than existing flexsplines. Furthermore, the use of a carbon fibre sheet and carbon fibre filaments provide good heat dissipation properties and prevents a buildup of heat in the flexspline and harmonic gear.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Figure (FIG.) 1 shows a cross section of a moulding apparatus to manufacture the flexspline.

[0026] FIG. 2 shows an enlarged part of FIG. 1.

[0027] FIG. 3 shows a view of the flexspline precursor prepared by the moulding process.

[0028] FIG. 4 shows a close-up view of the flexspline.

[0029] FIG. 5 shows a cross-sectional view of the flexspline.

[0030] FIG. 6 and FIG. 7 show outer exterior views of the flexspline.

[0031] FIG. 8 shows a side view of the flexspline.

DETAILED DESCRIPTION OF THE INVENTION

5 [0032] In the following description, numerous specific details are set forth in order to provide a thorough understanding of various illustrative embodiments of the invention. It will be understood, however, to one skilled in the art, that embodiments of the invention may be practiced without some or all of these specific details. Embodiments described in the context of one of the methods or devices are analogously valid for the other methods or
10 devices. Similarly, embodiments described in the context of a method are analogously valid for a device, and vice versa. A method may be described as various actions to be performed and do not require a specific sequence unless stated otherwise or required otherwise by the context.

[0033] Unless defined otherwise, all technical and scientific terms used herein have the
15 meaning commonly understood by a person skilled in the art to which this invention belongs. Unless otherwise specifically noted, articles depicted in the drawings are not necessarily drawn to scale.

[0034] As used herein, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements. As used herein, the
20 term “and/or” includes any and all combinations of one or more of the associated listed items. As used herein, the terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements on their objects. As used herein, the terms “top”, “bottom”, “left”, “right”, “side”, “vertical” and “horizontal” are used to describe relative arrangements of the elements and features. As used herein, the
25 term “each other” denotes a reciprocal relation between two or more objects, depending on the number of objects involved.

[0035] Terms such as “joined”, “connected”, “attached”, “bonded”, “conjugated and “linked” are used interchangeably herein and encompass direct as well as indirect connection, attachment, bond, linkage or conjugation unless the context clearly dictates
30 otherwise.

[0036] Where a combination is disclosed, each subcombination of the elements of that combination is also specifically disclosed and is within the scope of the invention. Conversely, where different elements or groups of elements are disclosed, combinations thereof are also disclosed. Where any element of an invention is disclosed as having a plurality of alternatives, examples of that invention in which each alternative is excluded singly or in any combination with the other alternatives are also hereby disclosed; more than one element of an invention can have such exclusions, and all combinations of elements having such exclusions are hereby disclosed.

[0037] Where a range of values is recited, it is to be understood that each intervening integer value, and each fraction thereof, between the recited upper and lower limits of that range is also specifically disclosed, along with each subrange between such values. The upper and lower limits of any range can independently be included in or excluded from the range, and each range where either, neither or both limits are included is also encompassed within the invention. Where a value being discussed has inherent limits, for example where a component can be present at a concentration of from 0 to 100%, or where the pH of an aqueous solution can range from 1 to 14, those inherent limits are specifically disclosed. Where a value is explicitly recited, it is to be understood that values which are about the same quantity or amount as the recited value are also within the scope of the invention, as are ranges based thereon.

[0038] Although each of these terms has a distinct meaning, the terms “comprising”, “consisting of” and “consisting essentially of” may be interchanged for one another throughout the instant application. The term “having” has the same meaning as “comprising” and may be replaced with either the term “consisting of” or “consisting essentially of”.

[0039] The term “substantially” as used herein refers to a great or significant extent. For example, it could refer to more than 50% or 75% and more. Preferably, it should refer to 80% or more, more preferably it should refer to 90% or more, even more preferably it should refer to 95% or more. A specific extreme example will be 100%, in other words “substantially” would also include all as the context specifies.

[0040] Described herein is a flexspline 200 made of a carbon-based composite material. FIG. 4 and FIG. 5 show close up views of an embodiment of the flexspline 200. FIG. 6,

FIG. 7, and FIG. 8 shows different views of the flexspline 200. Referring to FIG. 4 and FIG. 5, the flexspline 200 contains a flexible body 210 and a plurality of gear teeth 205 arranged on a surface of the flexible body 210. The flexible body 210 uses one or more sheets of carbon fibre as the base deformation material and carbon fibre filaments as the main material for the gear tooth 205.

[0041] The flexible body 210 is made of at least one sheet of carbon fibre (may also be termed a carbon fibre cloth) and substantially a first adhesive resin (may also be termed a flexible body adhesive resin). Each sheet of carbon fibre may be woven together with carbon fibre threads 212. For example, the sheet of carbon fibre may be woven with warp threads 212 of carbon fibre and weft threads 212 of carbon fibre to form the sheet as shown in an exposed part of the flexible body 210 in FIG. 7. In an embodiment, the gear teeth 205 may be positioned at about an angle of 45° to the warp threads 212 and weft threads 212. In an example, the flexible body 210 may contain one sheet of carbon fibre and in another example the flexible body may contain multiple sheets of carbon fibre layered together. Thus, the plurality of gear teeth 205 are also similarly arranged on the surface of the at least one sheet of carbon fibre. By layering or stacking together multiple carbon fibre sheets and bonded by the first adhesive resin in the flexible body 210, a flexible body 210 with different thickness may be prepared. Advantageously, the carbon fibre sheet provides high tensile strength, fatigue resistance, able to deform slightly but not easily, and it will not be damaged after multiple deformations. These characteristics make the carbon fibre sheet and resultant flexible body 210 suitable for use in the flexspline 200 and harmonic gear.

[0042] Each gear tooth 205 in the flexspline 200 contains carbon fibre filaments and substantially a second adhesive resin (may also be termed a tooth adhesive resin) to bond the carbon fibre filaments together. As an example, the carbon fibre filaments may have a length from 0.2 millimetres (mm) to 10 millimetres. The amount of carbon fibre filaments in each gear tooth 205 depends on and is determined by the size and/or strength required of the gear tooth 205. For example, a larger gear tooth 205 may require a greater amount of carbon fibre filaments and vice versa. In an embodiment, the carbon fibre filaments may be asphalt-based carbon filaments. Thus, the carbon fibre filaments may be derived from asphalt. The carbon fibre filaments and the second adhesive resin form the gear tooth 205

and is joined to the flexible body 210 at a tooth root 225. The end portion of the carbon fibre filaments in the tooth root 225 may be bonded by the first adhesive resin and may be considered embedded partly in the flexible body 210. The tooth root 225 attaches the gear tooth 205 to the sheet of carbon fibre. Advantageously, the carbon fibre filaments are self-lubricating, have good wear resistance and high strength and can withstand the continuous and prolonged impact and tangential force the gear teeth 205 of the flexspline 200 is subjected to when the harmonic gear is in used where the gear teeth 205 of the flexspline 200 constantly moves and engages with the outer spline in the harmonic gear. The properties of the carbon fibre filaments allow them to be a good choice of material to be used in the gear teeth 205 and solves the existing problem of the gear teeth 205 being rapidly worn out. The carbon fibre sheet and filaments have good heat transfer properties and are conducive to dissipate the heat generated in the harmonic gear and prevent overheating in the harmonic gear.

[0043] In an embodiment, the first adhesive resin and the second adhesive resin may be the same adhesive resin. In another embodiment, the first adhesive resin and the second adhesive resin are different. Different specifications of the adhesive resin may be used in the flexible body 210 and the gear tooth 205 by using segmented injection. For the first resin adhesive used for the flexible body 210 of the flexspline 200, materials with good toughness and elastic deformation after moulding are preferred and allows the flexible body 210 to undergo long-term deformation without being easily damaged. For the second resin adhesive of the gear teeth 205, a resin adhesive with high strength and high temperature resistance after moulding is preferred. When two different adhesive resins are used, the flexible body 210 and the gear teeth 205 should contain substantially the first adhesive resin and the second adhesive resin respectively as described herein. During the preparation, as both adhesive resins are likely to be added as liquids, there could be some mixing of both adhesive resins, hence it is possible that the flexible body 210 and gear teeth 205 may contain both adhesive resins but should have their respective adhesive resin as a substantial component. In both embodiments, the adhesive resin may be a thermosetting resin or a thermoplastic resin. Preferably, the adhesive resins have a temperature resistance of 300 °C and above to avoid the resin losing its material properties. The adhesive resins after solidification should provide a certain degree of

toughness but has the flexibility to be deformed. The bulk of the tensile strength should be provided by the carbon fibre filaments. The adhesive resin bonds the at least one sheet of carbon fibre to the plurality of gear teeth 205 in particular the carbon fibre filaments. After the adhesive resin solidifies in the moulding process, the at least one sheet of carbon fibre, carbon fibre filaments and adhesive resin may form a composite material, in other words a single body. Examples of suitable adhesive could be synthetic or natural adhesives and include epoxy resins, polyether ether ketone (PEEK) resin, silicone (also known as polysiloxane), other similar resins and any combinations thereof.

[0044] The plurality of gear teeth 205 are arranged spaced apart along the surface of the flexible body 210 and consequently the at least one sheet of carbon fibre. The flexible body 210 may have the carbon fibre filaments in the regions of the tooth roots 225 as seen in FIG. 4. In an embodiment, a majority or all of the plurality of gear teeth 205 is arranged equally spaced apart along the surface of the flexible body 210 or the sheet of carbon fibre. The spaces between the tooth roots 225 may be substantially free or essentially free of carbon fibre filaments and will thus be flexible and allow the flexible body 210 to deform and function as required by the flexspline 200 in the harmonic gear. When the spaces between tooth roots 225 and gear teeth 205 are substantially free or essentially free of carbon fibre filaments, the gear teeth 205 are unrestricted in their movement and can freely deform elastically. During the elastic deformation of the gear teeth 205, the tension of the at least one sheet of carbon fibre moves the gear teeth 205 up and down. The overall view observed is that the flexspline 200 is constantly changing, elliptical deformation in one direction.

[0045] The flexible body 210 of the one or more sheets of carbon fibre, the carbon fibre filaments in the gear teeth 205 and adhesive resin/s are combined together using a moulding apparatus 100 such that the carbon fibre sheet/s, carbon fibre filaments and adhesive resin/s are tightly combined together to form a composite material that forms the main component of the flexspline 200.

[0046] A metal support 215 may be attached to the flexible body 210 on the opposite surface of the flexible body 210 from the gear teeth 205, in particular the metal support 215 may be attached to a second surface of the at least one sheet of carbon fibre which is opposite from the first surface of the at least one sheet of carbon fibre attached to the gear

teeth 205. The flexible body 210 may be viewed as attached to the exterior surface of the metal support 215 (see FIG. 6 and FIG. 7) whilst the interior of the metal support 215 houses part of the shaft of the harmonic gear (see FIG. 6) and the interior surface of the metal support 215 faces the shaft. As shown in FIG. 6 a substantial (all or a large) part of the exterior surface of the metal support 215 is attached to and covered by the flexible body 210. Alternatively, the flexible body 210 may be present largely or only in the region where the gear teeth 205 are located. Hence, the flexible body 210 may be between the gear teeth 205 and the metal support 215. The metal support 215 may be attached to the flexible body 210 by the first adhesive resin. In an embodiment, the metal support 215 may be a cylindrical structure or a frustoconical structure. A frustoconical structure refers to a truncated conical structure or a conical structure with the pointed end removed. The angle 230 of the slanted part of the frustoconical structure and the horizon (seen in FIG. 8) may be determined based on the size of the gear teeth 205 and the diameter of the flexspline 200. In an example, the angle 230 may be from 91 to 100 degrees with both ends inclusive, a specific non-limiting example of the angle 230 may be 92 degrees.

[0047] In an embodiment, one (a first) region of the cylindrical structure is attached to the gear teeth 205 with the flexible body 210 in between and the other (second) opposite region 217 of the cylindrical structure is attached to a shaft in the harmonic gear. In another embodiment, one (a first) region of the frustoconical structure is attached to the flexible body 210 and the other (second) opposite region 217 of the frustoconical structure is attached to a shaft in the harmonic gear. In both of these embodiments, the opposite regions 217 of the cylindrical structure and the frustoconical structure is preferably attached to the shaft via the metal flange 220 described herein and may be preferably thicker than the region attached to the flexible body 210, in other words the other opposite regions 217 are thicker. The metal support 215 may be a thin-wall cylinder with a thick bottom 217 or a thin-wall frustoconical shaped cylinder with a thick bottom 217. The thick bottom 217 allows for ease of connection to a shaft in the harmonic gear. The metal support 215 should be flexible to allow it to bend with the flexible body 210 yet provide sufficient strength. The shaft may be for output transmission or input transmission in the harmonic gear. The thinner portion of the cylindrical structure is mainly for supporting the sheet of carbon fibre. In an example, the metal support 215 like the cylinder may have a

thickness of 0.05 to 3 millimetres (mm). As an example, the thick bottom 217 may have a thickness of about 1 to 3 mm, while thinner portion may have a thickness of 0.05 to 1 mm. Advantageously, the metal support 215 improves the stability of the flexspline under high torque working conditions but may not be required for all uses.

5 [0048] A metal flange 220 may be attached to the flexible body 210 on the same side as the gear teeth 205. The metal flange 220 may be connected to the output end of the flexspline 200 via a shaft channel 235 and is able to withstand large torques endured by the harmonic gear when it is used. The metal flange 220 may have one or more flange channels 237 as seen in FIG. 6 and FIG. 7. The flange channels 237 allow the adhesive resin to be injected when the flexspline 200 is being formed in and to attach the flexspline 200 to the shaft in the harmonic gear. Bolts may be later inserted into the flange channels 237 to attach the metal flange 220 and metal support 215 to the shaft. The metal flange 220 supports the sheet of carbon fibre and clamps the sheet/s of carbon fibre. The metal flange 220 is attached to the flexible body 210 and metal support 215 by the flexible body adhesive resin. The metal flange 220 should be rigid and is mainly used to transmit torque. The metal flange 220, flexible body 210, metal support 215 and flexible body adhesive resin may be tightly bonded together by compressing with a moulding apparatus 100.

10 [0049] FIG. 1 shows a cross-section of a moulding apparatus 100 for preparing a flexspline 200 described in the embodiments herein. FIG. 2 shows an expanded view of the circled part A in FIG. 1. FIG. 3 shows a view of the flexspline 200 obtained from the moulding process. The flexspline 200 may be prepared by a moulding and pressure injection process. The moulding apparatus 100 has an outer mould 115, an inner mould 120, a compression mould 110, a vacuum port 105, and a resin injection inlet 130. A plurality of gear tooth cavities is formed by the outer mould 115, inner mould 120, and compression mould 110 that are used to form the gear teeth 205 in the flexspline 200. As may be seen in FIG. 1, the outer mould 115 and inner mould 120 both have a general U-shaped cross section. The top ends 117 of the U-shaped cross section of the outer mould 115 may have a plurality of channels. The channels 117 of the outer mould 115 together with the inner mould 120 and compression mould 110 forms a gear tooth cavity that may be filled with carbon fibre filaments to form the gear teeth 205 in the flexspline. The outer mould 115 may also have a groove to accommodate a metal flange 220. Hence, the inner

mould 120 and outer mould 115 are configured such that when they are arranged in position the inner mould 120 and outer mould 115 form a space between them to receive the sheet/s of carbon fibre and a plurality of gear tooth cavities at the top of the inner mould 120 and outer mould 115. The compression mould 110 is configured to be inserted
5 into the opening of the gear tooth cavities to close and pressure the carbon fibre filaments placed in the gear tooth cavities. The outer mould 115 may have one or more injection holes 135 in fluid communication with the resin injection inlet 130 and allows the adhesive resin to flow from the resin injection inlet 130 into the space between the inner mould 120 and the outer mould 115, and may be through the shaft channel 235 and flange channels
10 237 in the metal flange 220.

[0050] To prepare the flexspline 200, a sheet or multiple sheets of carbon fibre is placed between the inner mould 120 and the outer mould 115 to provide the flexible body 210. The thickness of the flexible body 210 and flexspline 200 may be varied by increasing or decreasing the number of sheets of carbon fibre. The required thickness of
15 the flexible body 210 and flexspline 200 will depend on the torque to be transmitted in the harmonic gear and thus can be varied according to the specific requirements of the harmonic gear. In an embodiment, if the metal support 215 is present the metal support 215 is placed on the inner mould 120 and the sheet of carbon fibre is placed on the metal support 215.

[0051] In an example, the metal support 215 may be laid on the outer wall 121 of the inner mould 120 and the one or more sheets of carbon fibre are placed over the metal support 215. This is subsequently placed in the outer mould 115 such that the metal support 215 and one or more sheets of carbon fibre are in a space between the inner mould 120 and the outer mould 115. This will also form the gear tooth cavities at the top of the
25 inner mould 120 and outer mould 115 as explained further below. The metal flange 220 may be inserted into a groove in the outer mould 115.

[0052] The outer wall surface 121 of the inner mould 120 may have an inclined angle to allow the sheet of carbon fibre and metal 215 to be placed at an inclined angle. Advantageously, this facilitates the placement of the sheet of carbon fibre, compression
30 process and release of the compressed product and sheet of carbon fibre.

[0053] The placement of the inner mould 120 and outer mould 115 forms the gear tooth cavities with an opening with the inner mould forming one surface of each gear tooth cavity whilst the channel 117 of the outer mould forms the other surfaces of the gear tooth cavity. Carbon fibre filaments are placed in or poured into the open gear tooth cavities and
5 a filter 125 is placed on top of the carbon fibre filaments in the gear tooth cavities. The filter 125 should have uniform pores with high filtration accuracy and efficiency. As an example, the filter 125 may be a filter ring and may have a metal powder sintered sheet structure. Based on the particle size of the carbon fibre filaments, a filter (or the metal powder sintered sheet) with different filtration accuracy may be selected.

10 [0054] The compression mould 110 is subsequently inserted into the inner mould 120 and the outer mould 115. The compression mould 110 is thus inserted into the opening of the gear tooth cavities to close and press against the filter and carbon fibre filaments in the gear tooth cavities.

[0055] The compression mould 110 may be provided with a vacuum line 107
15 connected to a vacuum port 105. The vacuum line 107 may be a channel or through hole in the compression mould 110. The vacuum line 107 connects the vacuum port 105 to the gear tooth cavities to remove air gaps in the gear tooth cavities and gear teeth 205 during their preparation. Each gear tooth cavity should have a vacuum line 107 and may be joined to a common vacuum line before connecting to the vacuum port, or each vacuum line 107
20 may be individually connected to a vacuum port 105, or a few vacuum lines 107 may be connected to a vacuum port 105. The vacuum line 107 thus provides fluid communication between the gear tooth cavities in the moulding apparatus 100 and the vacuum port 105. This allows the moulding apparatus 100 and moulding process to be subjected to vacuum treatment to remove air from the gaps in the carbon fibre filaments during the formation of
25 the gear teeth 205 in the moulding process.

[0056] An adhesive resin is injected into the moulding apparatus 100 through the resin injection inlet 130 and injection holes 135 in the outer mould 115. Due to the pressure of the injection, the liquid adhesive resin flows through the moulding apparatus and fills the spaces between the inner mould 120, outer mould 115, sheet of carbon fibre, metal flange
30 220 and metal support 215 if either or both are present, and carbon fibre filaments in the gear tooth cavities. The liquid adhesive resin subsequently flows out of the filter 125.

Under the vacuum conditions and with the injection of the adhesive resin, the filter 125 can aid the compression of the carbon fibre filaments and adhesive resin to aid the compact formation of the gear tooth 205. The filter 125 allows gas and liquid adhesive resin to pass through whilst trapping the carbon fibre filaments within the gear tooth cavities and can effectively maintain the stability of the carbon fibre filaments and for the sheet of carbon fibre and carbon fibre filaments to be evenly distributed and bonded without air bubbles and holes in the flexspline 200 formed in the moulding process.

[0057] The adhesive resin may be injected via a resin injection inlet 130 of the outer mould 115, for example the bottom region of the outer mould 115 as shown in FIG. 1, however other arrangements are possible to achieve the same result. The adhesive resin bonds to the sheet of carbon fibre and if multiple sheets of carbon fibres are used bonds them together to form the flexible body 210. The adhesive resin also bonds the flexible body 210 and hence the carbon fibre sheet to the metal support 215 if it is present. The adhesive resin also bonds the carbon fibre filaments together to form each gear tooth 205 and bonds each gear tooth 205 to the flexible body 210 via the tooth root 225. The tooth root 225 may be considered to be the part of the gear tooth 205 with carbon fibre filaments and adhesive resin attached to the flexible body 210.

[0058] According to different usage conditions and requirements of the harmonic gear, different types of resins may be used such as a thermosetting resin or a thermoplastic resin. In an embodiment, the same adhesive resin is used for both flexible body 210 and the gear teeth 205. In another embodiment, different adhesive resins are used for the flexible body 210 and the gear teeth 205 as described earlier and segmented injection may be used to inject the first adhesive resin to the flexible body 210 and the second adhesive resin to the gear teeth 205.

[0059] The inner mould 120 and outer mould 115 thus compress the sheet of carbon fibre and resin adhesive to form the flexible body 210 and additionally if present the metal support 215 and metal flange 220. The compression mould 110 compress the carbon fibre filaments, adhesive resin and the filter 125 to form the gear teeth 205 and also to bond the gear teeth 205 to the flexible body 210 via the tooth root 225. The tight bonding of the components of the flexible body 210 and gear teeth 205 provide a flexspline 200 which is extremely strong and durable with high shear strength and can be further processed.

[0060] After the liquid adhesive resin solidifies, the inner mould 120, outer mould 115, and compression mould 110 are removed to form the flexspline 200 with the tightly combined components. The flexible body 210 in the form of the at least one sheet of carbon fibre is held and tightened together by the metal flange 220 and the thick end 217 of the metal support 210 and are bonded together by the adhesive resin. The flexspline 200 may be further machined. For example, the filter 125 remains on the gear tooth 205 and needs to be machined off to form the flexspline 200. The metal flange 220 region may need further processing after the moulding process. The sheet of carbon fibre may be pressed into the metal flange 220 and may need to be smoothened. The shaft channel 235 and flange channels 237 may also need to be smoothened to remove excess adhesive resin and/or carbon fibre sheets. Alternatively, additional flange channels 237 may be added. Bolts may be later inserted in the flange channels to tightly attached together the metal flange 220, flexible body 210 and metal support 215.

[0061] Advantageously, the teeth 205 of the flexspline 200 formed by the carbon fibre filaments are able to withstand large radial loads that occurs during the use of the harmonic gear. The carbon fibre filaments have self-lubricating properties, high strength, high wear resistance and good heat dissipation. The attachment of the gear teeth 205 to the sheet of carbon fibre with the adhesive resin via the tooth root 225 provides for a composite material and flexspline 200 with high strength and can withstand a larger load.

CLAIMS

[Claim 1] A flexspline comprising at least one sheet of carbon fibre; a plurality of gear teeth arranged along and attached to a surface of the at least one sheet of carbon fibre; and an adhesive resin to attach the at least one sheet of carbon fibre to the plurality of gear teeth, each gear tooth in the plurality of gear teeth comprises carbon fibre filaments and the adhesive resin.

[Claim 2] The flexspline according to claim 1, comprising a metal support, a second surface of the at least one sheet of carbon fibre is attached to the metal support with the adhesive resin, the second surface is opposite to the surface attached with the plurality of gear teeth.

[Claim 3] The flexspline according to claim 2, wherein the metal support comprises a cylindrical structure with a first region attached to the plurality of gear teeth via the at least one sheet of carbon fibre and a second opposite region or a frustoconical structure with a first region attached to the plurality of gear teeth via the at least one sheet of carbon fibre and a second opposite region, preferably the second opposite region of the cylindrical structure and the second opposite region of the frustoconical structure is thicker than the respective first region.

[Claim 4] The flexspline according to claim 3, comprising a metal flange attached to the second opposite region of the cylindrical structure or the second opposite region of the frustoconical structure.

[Claim 5] The flexspline according to claim 4, wherein the metal flange comprises a shaft channel to allow attachment to a shaft and one or more flange channels.

[Claim 6] The flexspline according to any one of claims 1 to 5, wherein the carbon fibre filaments have a length from 0.2 millimetre to 10 millimetres, preferably the carbon fibre filaments are asphalt-based carbon fibre filaments.

[Claim 7] The flexspline according to any one of claims 1 to 6, wherein the plurality of gear teeth is arranged spaced part along the surface of the at least one sheet of carbon

fibre such that a space between adjacent gear teeth is substantially free of carbon fibre filaments, preferably the plurality of gear teeth is arranged equally spaced apart along the surface of the at least one sheet of carbon fibre.

- 5 [Claim 8] The flexspline according to any one of claims 1 to 7, wherein the at least one sheet of carbon fibre is attached to the plurality of gear teeth at an angle of about 45°.

- [Claim 9] The flexspline according to any one of claims 1 to 8, wherein the adhesive resin comprises a first adhesive resin and a second adhesive resin, the first adhesive resin
10 is substantially applied on the at least one sheet of carbon fibre, the second adhesive resin substantially bonds the carbon fibre filaments in each gear tooth.

- [Claim 10] The flexspline according to any one of claims 1 to 9, wherein the adhesive resin is a thermosetting resin or a thermoplastic resin and/or the adhesive resin has a
15 temperature resistance of 300 °C and above.

- [Claim 11] The flexspline according to any one of claims 1 to 10, wherein the adhesive resin is selected from the group consisting of an epoxy resin, a polyether ether ketone (PEEK) resin, silicone, and any combinations thereof.

- 20 [Claim 12] The flexspline according to any one of claims 1 to 11, wherein the adhesive resin, the at least one sheet of carbon fibre and the carbon fibre filaments form a composite material.

- 25 [Claim 13] The flexspline according to any one of claims 1 to 12, wherein a plurality of sheets of carbon fibres are layered together.

- [Claim 14] A method of preparing a flexspline, the method comprising
placing at least one sheet of carbon fibre between an inner mould and an outer
30 mould;
placing carbon fibre filaments in a plurality of gear tooth cavities formed between the inner mould and the outer mould;
injecting an adhesive resin to bond the at least one sheet of carbon fibre and carbon fibre filaments placed between the inner mould and the outer mould; and

compressing the sheet of carbon fibre, the carbon fibre filaments and the adhesive resin with a compression mould.

5 [Claim 15] The method according to claim 14 comprising applying a vacuum during injecting the adhesive resin and/or compressing the at least one sheet of carbon fibre, the carbon fibre filaments, and the adhesive resin with the compression mould.

10 [Claim 16] The method according to claim 14 or claim 15, wherein injecting the adhesive resin comprises injecting a first adhesive resin to the at least one sheet of carbon fibre and injecting a second adhesive resin to the carbon fibre filaments in the plurality of gear tooth cavities.

15 [Claim 17] The method according to any one of claims 14 to 16 further comprising placing a metal support on the inner mould and the sheet of carbon fibre on the metal support.

20 [Claim 18] The method according to claim 17 or claim 18 further comprising placing a metal flange in a groove of the outer mould, wherein the metal support is arranged to be attached to the plurality of gear teeth via the at least one sheet of carbon fibre at a first region and the metal support is arranged to be attached at a second opposite region to the metal flange; and placing a filter at an end of each of the gear tooth cavities to allow gas and excess adhesive resin to flow out.

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30 [Claim 19] A harmonic gear comprising a rigid spline having a second plurality of gear teeth; the flexspline according to any one of claims 1 to 13; and a wave generator that engages the flexspline such that a movement of the wave generator moves the flexspline and vice versa, wherein the plurality of gear teeth of the flexspline engages with the second plurality of gear teeth of the rigid spline such that a movement of the flexspline moves the rigid spline and vice versa, wherein the plurality of gear teeth of the flexspline is less than the second plurality of gear teeth of the rigid spline.

[Claim 20] A moulding apparatus to prepare a flexspline, the moulding apparatus comprising an inner mould, an outer mould, a compression mould, and an resin injection inlet, wherein the inner mould and outer mould are configured to be placed together to form a space to receive at least one sheet of carbon fibre and a plurality of gear tooth cavities to receive carbon fibre filaments, the compression mould is configured to be inserted into the plurality of gear tooth cavities, and the resin injection inlet is in fluid communication with the space and the plurality of gear tooth cavities.

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