Title: METHOD OF RECYCLING DISCARDED RUBBER PRODUCTS, PARTICULARLY OF TYRES, EQUIPMENT FOR CARRYING OUT THIS METHOD AND CRUSHING KNIFE

Abstract: Method of recycling tyres or other discarded rubber products, so as of conveyor belts, where the tyres supplied are sorted and checked, then the tyres are separated into beads (5) with the wire beads, sidewalls (4) and tread (3) by water jet in the first stage, the separated sidewalls (4) and tread (3) are separately conveyed to the second stage of cutting by water jet to pieces of uniform size, the cut pieces are frozen, then crushed to a mixture of structure with fully separated individual fractions, the mixture is left to settle down and is then sorted to individual fractions, i.e. textile lint, metal, rubber granulate, and eventually, the finest textile fluff is removed from the final granulate. Equipment for recycling comprises a device for controlling of liquid nitrogen level height in the freezing chamber, which freezing chamber is formed by a controlling chamber interconnected with the freezing chamber on the principle of interconnected vessels, where the controlling chamber is provided with liquid nitrogen level height sensors, which sensors are connected to an electromagnetic valve of a liquid nitrogen storage tank for opening/closing input of nitrogen into the controlling chamber. Crushing knife for crushing of material in a chamber comprising a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor and in a cross-section along a plane perpendicular to the axis of the through hole the leading edge (2) of the knife (1) has a convex or concave form, which convex or concave form of the leading edge (2) is formed by a part of logarithmic spiral or Archimedes’
METHOD OF RECYCLING DISCARDED RUBBER PRODUCTS, PARTICULARLY OF TYRES, EQUIPMENT FOR CARRYING OUT THIS METHOD AND CRUSHING KNIFE

Field of the Invention

The present invention relates to a method of recycling discarded rubber products, particularly of tyres, to equipment for carrying out this method and to a crushing knife for this equipment.

Background of the Invention

Various methods of total processing of waste rubber products, both the worn out and the rejects, for example of tyre casings, conveyor belts etc., are known. Such methods comprise both the destructive methods (burning, pyrolysis) and the non-destructive methods, which non-destructive methods allow using of this polymeric secondary raw material by recycling it into the production process.

The relatively effective mechanical crushing of worn out tyre casings at normal temperature does not allow to process tyre casings with steel cord. However, quantity of the tyre casings with steel cord substantially prevails in comparison with the quantity of the tyre casings with textile cord.

Therefore, crushing at deep temperatures was put into practice. However, this method exhibits some disadvantages with regard to energy consumption and only the high-capacity plants are advantageous with regard to the energy consumption. Further, continual operation of such plant is required and consequently
big volumes of worn out tyre casings have to be supplied continuously. The steel cord reinforcement is chemically treated to obtain the necessary rubber-steel adhesion. The so treated steel is not suitable for metallurgical steel recovery processes.

Document CZ 7959 U discloses equipment for recirculation disposal of tyres, which equipment comprises a freezing tunnel, a crushing device with a grate, on which grate the tyres are crushed by means of a pressing device. The steel cord is removed from the grate and the tyre pieces fall through the grate to be then crushed to powder.

Document WO 97/07893 discloses a method of recycling tyres comprising the first-step destruction by cutting to pieces, freezing of the pieces and the second-step crushing, sorting to sort out big pieces of rubber or polymer from the mixture and sorting out of metal and textile from the mixture. The freezing can be carried out either indirectly in freezing chambers of various design or directly continually by spraying of the freezing medium or by immersing in the freezing medium. Liquid nitrogen is preferably used as the freezing medium. The problem is that the liquid nitrogen is transferred from a pressure storage tank to a vessel at atmospheric pressure. The liquid nitrogen instantly starts to vaporize into the gaseous state. Temperature of the rubber pieces immersed into the liquid nitrogen is above 0°C, i.e. about 0 to 20°C. Therefore, constant liquid nitrogen level height has to be provided in the freezing chamber. The liquid nitrogen temperature is -196°C. Considering the extremely low temperature in the freezing chamber, it is difficult to provide a controlling equipment being able to ensure monitoring of the required liquid nitrogen level height,
which controlling equipment has to be operable at such extremely low temperatures.

Further, document BG 105 473 discloses a method of recycling tyres, which method comprises separation of the tyre bead, circumferential pressing of the tyre and making the tyre flat, cutting of the pressed tyre to transverse strips, crushing of the strips with separation of metal and rubber, and separation of metal from rubber.

Document WO 01/17733 (priority from the documents FR 2 798 090, FR 2 811 915, FR 2 798 089) discloses a method of recycling tyres, which method comprises gradual cutting of a tyre and is oriented to recovery of the high-quality rubber. The method comprises separation of the tread from the two sidewalls by using a high-pressure water jet. The cutting is carried out from the inside of the tyre in radial direction and in liquid environment, above a vessel with liquid, e.g. water, with the objective to obtain rubber granulate of particle size maximally 12 micrometers. The granulate is then purified by flotation.

To carry out material destruction by crushing in a chamber various models of rotating tools are used. The material is crushed by direct contact of said material with a tool and by contact with the chamber jacket, in which chamber the tools are situated. Further, the crushing is allowed also by rubbing the material together, by rubbing the material against the walls, by centrifugal forces, by turbulences, etc.

Movement trajectories of the material particles are determined by the angular velocity magnitude of the functional tool
surfaces above 800 km/h and also by the form of the tool working part.

The already disclosed crushing knifes comprise a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor. In a cross-section along a plane perpendicular to the axis of the through hole, the leading edge of the knife has a convex, concave or linear form.

In case of the linear tools, if there is a contact of the material with the tool, the material slips along the leading edge, what decreases the crushing effect. Further, the crushed material is heated up by friction against the leading edge. The material crushing effect is very low. By crushing of elastic materials (tyre rubber, cable rubber, plastics) at normal temperatures without freezing the energy consumption increases, the crushing segments wear down, the material is crushed to such particle size that separation to individual components (metallic wire, textile fibres and rubber) is nearly impossible and economically ineffective. To boost the effect various cryogenic methods are used, which methods comprise freezing of the material so that the material becomes brittle. Thereafter, by rubbing of the material against the tool and by rubbing of the material together, the material is rapidly heated up and the required brittleness is lost, whereby, the crushing effectiveness is decreased significantly.

The above-mentioned disadvantages do not appear in case of tools with convex or concave leading edge, but in the crushing process their disadvantage is that their curvature form is not optimal.
An effective non-destructive method of total processing of discarded rubber products, tyre casings, providing a total processing of said waste products at acceptable energy and investment costs and by using a suitable technical solution has not been disclosed yet.

**Summary of the Invention**

The present invention relates to a method of recycling tyres or other discarded rubber products, so as of conveyor belts, with the objective to re-use individual components of a tyre without modifying their nature. The tyres are separated by water jet into beads with the wire beads, sidewalls and tread in the first stage. The separated sidewalls and tread are separately conveyed to cutting by water jet to pieces of uniform size. The cut pieces are frozen, then crushed by cutting to produce a mixture of rubber granulate, metal and textile. The mixture is left to settle down and is then sorted to individual components: rough textile lint, metal, fractions of rubber granulate of various particle size. Eventually, the finest textile fluff is removed from the final granulate.

The method of recycling tyres, or other discarded rubber products, so as of conveyor belts according to the present invention comprises sorting and checking of the supplied tyres, which tyres are then at first separated in the first stage by water jet into beads with wire beads, sidewalls and tread, whereupon, the sidewalls and the tread are separately conveyed into the second stage of separating by water jet cutting to pieces of uniform size, the cut pieces are frozen, then crushed to produce a mixture of such structure that complete separation
to individual fractions takes place, the mixture is left to settle down and then the mixture is sorted into individual fractions, textile lint, metal, rubber granulate, whereupon, the finest textile fluff is eventually removed from the final granulate.

The freezing is carried out continually in a freezing chamber with a charge of liquid nitrogen whilst controlling a stable liquid nitrogen level height in the chamber.

Disintegration by crushing is carried out in a destruction chamber by charging cut frozen pieces and crushing them.

The crushed mixture of fractions is blown out of the destruction chamber into a settling chamber, which setting chamber is having the volume corresponding to the output of the destruction chamber, to slow down the flow of the blown out mixture to a velocity required to settle down fractions of the mixture and the air blown out is further led via a cyclone and an exhaust filter, where the finest particles of rubber and textile lint are captured.

Rough lint is separated from wires and rubber on sieves with mesh size 10 to 12 mm.

Steel wires are separated electromagnetically.

Rubber granulate is sorted to fractions according to particle size as required.
The finest textile fluff is separated from the final rubber granulate in separation equipment, for example of the fluid plate design.

Equipment for recycling of discarded rubber products to carry out the method mentioned above comprising a freezing chamber and a storage tank for liquid nitrogen is characterized in that it comprises a device for controlling of liquid nitrogen level height in the freezing chamber, which freezing chamber is formed by a controlling chamber interconnected with the freezing chamber on the principle of interconnected vessels, where the controlling chamber is provided with liquid nitrogen level height sensors, which sensors are connected to an electromagnetic valve of a liquid nitrogen storage tank for opening/closing input of nitrogen into the controlling chamber.

The crushing knife for crushing of material in a chamber comprising a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor and in a cross-section along a plane perpendicular to the axis of the through hole the leading edge of the knife has a convex, concave or linear form, is characterized in that the form of the leading edge is formed by a part of logarithmic spiral or Archimedes' spiral or by a part of a circle evolvent.

In another possible embodiment of the crushing knife the concave form of the leading edge is formed by a part of logarithmic spiral or Archimedes' spiral or by a part of a circle evolvent.

An advantage of the method according to the present invention is a significant decrease of investment costs, operation costs and
energy consumption and that high ratio of the rubber granulate granularity per unit of energy consumed in the whole process is obtained.

Better result in separating individual fractions of recycling is obtained because in cutting by water jet to pieces of the same size after crushing of the pieces the wire pieces in the recyclate mixture are significantly smaller than those in comparable recycling methods. This allows their better separation from the textile lint.

A new product of the recycling are undamaged rubber beads with wire beads that can be used as a reinforcement necessary in building of bridges, roads, etc. what increases lifetime of such structures severalfold.

The device for controlling liquid nitrogen level height in the freezing chamber according to the invention, considering the extremely low temperatures in the freezing chamber, is a controlling device able to provide monitoring of the required liquid nitrogen level height and is operable at such extremely low temperatures and to provide so a constant liquid nitrogen level height in the freezing chamber.

An advantage of the knife leading edge in the form of a logarithmic or Archimedes' spiral or in the form of a circle evolvent that it provides higher crushing effect in direct contact of knife with the crushed material at the same energy consumption. The effect of material slipping and friction along a straight tool is removed. Therefore, the crushing effect is fully used in direct contact of the tool with the crushed
material and energy is saved significantly. A result is that the crushing is very effective. When the curved edges are used, the temperature increase of the crushed material is significantly intensified. The crushing effect is severalfold higher and the required energy input to drive the rotating tools is lower in the order of several tenths of percents.

Brief Description of the Drawings

The invention in its various aspects will now be described with reference to certain drawings thereof, in which:

Figure 1 is a fragmentary top plan view of a crushing knife with convex leading edge, which edge is formed by a part of a logarithmic spiral and

Figure 2 is a fragmentary top plan view of a crushing knife with concave leading edge, which edge is formed by a part of an Archimedes' spiral.

Figure 3 is a schematic view of a tyre separation in the first stage of separation by water jet to three basic parts.

Detailed Description of the Invention

In a particularly preferred embodiment of the present invention, the method of recycling tyres or other discarded rubber products, so as of conveyor belts, comprises recycling, i.e. repeated use of individual tyre components without modifying their composition. Tyres are separated to beads with wire beads, sidewalls and tread by water jet in the first stage. The
separated sidewalls and tread are separately cut to pieces of uniform size by water jet. The cut pieces are frozen and then crushed by cutting to obtain mixture of rubber granulate, metal and textile. The mixture is left to settle down and then it is sorted to individual components - rough textile lint, metal, rubber granulate fractions of different particle size - and eventually the finest textile fluff is removed from the resulting granulate.

The discarded tyres are checked and sorted according to their grade (car tyres, truck tyres, off-road tyres, etc.), according to their seasonal use (all-seasonal, winter). Eventually, the tyres can be sorted out also according to the producer's make. During sorting the tyres are also checked, particularly to sort out undesired foreign matter (e.g. stones, glass, metal pieces, etc.), what would make the proper recycling more difficult or would deteriorate the final products of recycling (acids, crude oil products, etc.).

The two-step cutting by water jet is carried out in two stages.

The first stage of tyre cutting is carried out in a handling line, which handling line feeds the sorted out tyres into the process of cutting by water jet. The tyres are separated into three basic parts - the beads 5 with wire beads, the sidewalls 4 and the tread 3.

This cutting is carried out to obtain undamaged beads 5, which beads 5 are formed by a wire bead encapsulated in rubber. The wire beads are produced from very strong steel wires. Tensile strength of the steel wires is 5-times higher than that of usual
steel reinforcements in the building industry. The so obtained beads 5 are suitable as reinforcements in environments where the structures are deteriorated by corrosion of reinforcements (e.g. bridges, water structures, roads, etc.).

Separation of the sidewalls 4 from the tread 3 makes the subsequent recycling process simpler because the tread 3 comprises wire carcass. The sidewalls 4 contain carcass only rarely. In the recycling process the sidewalls 4 are processed to obtain pure textile lint without any fractions of steel wires what is required in the secondary use of this textile lint for example in processing to nonwoven fabrics, etc.

Separation of tyres to sidewalls 4 and tread 3 is also important in the second stage of separation – cutting by water jet – also because there are other operation costs in the process of recycling (recycling equipment wear, energy consumption demands, recycling line output, separation of metallic parts from the recyclate mixture).

Therefore, the other stage of tyre separating by water jet cutting is carried out separately for sidewalls 4 and tread 3. The separated sidewalls 4 and tread 3 are separately fed to cutting to pieces of uniform size, the size being suitable for the proper process of crushing the tyres to individual components (rubber, textile cord – lint, steel wires).

Therefore, after separation of the bead 5 with the wire bead, which bead 5 is already applicable as reinforcement in concrete, etc., in this form, in this two stage separation, the sidewalls 4 and the tread 3 are separately cut to small pieces. Because
the sidewalls 4 do not contain wires, the method of separating rubber from textile will be different than that used in case of treads, where after destruction it is necessary to separate rubber, textile and wire in a sorting equipment.

Separated cutting of the tyre sidewalls 4 and the treads 3 is also necessary because the cutting rate (at the same pressure and the same jet diameter) is several times slower in case of the treads 3 containing a wire carcass than that in case of the sidewalls 4 containing only rubber and textile.

The tread 3 and sidewall 4 fractions then pass into the next step separately. This step is continual cryogenic (i.e. at deep temperatures) crushing of individual components (rubber, textile cord - lint, steel wire), which crushing is carried out separately for the sidewalls 4 and for the tread 3.

The components cut are then deep-frozen to a temperature providing brittleness, which brittleness is necessary to carry out a low-energy crushing.

This crushing is preferred to grinding of non-frozen rubber, because it is less energy demanding, lifetime of the recycling equipment is higher, and the output is several times higher.

Freezing can be carried out either indirectly in freezing chambers of various models or directly by spraying of the freezing medium or by immersing into the freezing medium. The most convenient is liquid nitrogen.
By freezing them, the components become brittle what facilitates the proper process of crushing to the basic fractions and provides high ratio of recycled rubber with particle size below 1 mm in one step of recycling.

The proper recycling is carried out by crushing in a destruction chamber. Rubber frozen to a temperature making it brittle, what is necessary to carry out a low-energy crushing, is fed to the destruction chamber. In the crushing chamber, rubber is crushed to such structure that it is entirely crushed into individual fractions - rubber granulate, fractions of steel wires and textile lint. In the crushing chamber, the components are cut by a system of special slats as described below.

The obtained mixture is then conveyed into a settling chamber, which settling chamber is special with regard to the crumb nature, in which crumb the lint increases its volume severalfold and forms big lumps with wire fragments. This lint tends to clog exhaust of the destruction chamber. Therefore, it is not possible to use standard cyclone to slow down the air flow to a level allowing all textile lint and fine fractions of rubber granulate to settle.

Settling takes place so that the mixture of crushed fractions is blown out of the destruction chamber at high speed - tenths of m/s - through an exhaust, which exhaust is having diameter from several cm up to several tenths of cm. To slow down the material flow the exhaust mouths into a settling chamber. Volume of this settling chamber is in units to tenths of m³ - according to the installed output of the destruction chamber so that the air leaving the destruction has low velocity to allow settling of
small rubber particles and textile lint. Because of their weight, wires settle without any problems. The slowed down blown out air is led from the settling chamber further via a cyclone or a set of cyclones and an exhaust filter.

From the storage tank the crushed mixture is transported to sorting.

Sorting to individual fractions - rubber granulate, lint, wires - is carried out separately for the sidewalls 4 and for the tread 3 so that on sieves of mesh size about 10 to 12 mm the rough lint is separated from the wires and rubber. The steel wires are sorted out electromagnetically. On a set of sieves the rubber granulate is sorted to fractions according to particle size as required. Eventually, the finest textile fluff is removed from the final granulate in a separation equipment for example of the fluid plate design.

In a direct continual freezing of rubber by means of liquid nitrogen, there is a problem that the liquid nitrogen is fed from a pressure storage tank into a vessel with common atmospheric pressure, where the nitrogen starts to boil immediately and evaporate into gaseous state. Therefore, it is necessary to provide constant liquid nitrogen level height in the freezing chamber at nitrogen temperature about -196°C. Because temperature of the pieces of rubber brought into the liquid nitrogen is above 0°C, usually about 0 to 20°C, and considering the extremely deep temperature in the freezing chamber, it is difficult to provide an operable controlling device being able to provide a reliable monitoring of the
required liquid nitrogen level height at so extremely deep temperatures.

According to this invention, this problem is solved by using a controlling chamber, which controlling chamber is interconnected with the freezing chamber, and the level height is controlled on the principle of joined vessels. In the controlling chamber, where the level is smooth, the level height is controlled by means of sensors operating in liquid nitrogen environment, for example by laser sensors, capacity sensors, magnetic sensors, etc. The sensors control an electromagnetic valve for opening and closing the liquid nitrogen supply from the storage tank into the freezing chamber space.

Various rotating tools are used for destruction of the material by crushing in a chamber. The material is crushed by direct contact with the tool and by contact with the chamber jacket, in which chamber the tools are placed. The crushing is caused also by influences like by rubbing the material together, by rubbing the material against chamber walls, by centrifugal forces, by turbulences, etc.

Movement trajectories of the material particles are determined by the angular velocity magnitude of the functional tool surfaces above 800 km/h and also by the form of the tool working part.

The already disclosed crushing knifes comprise a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor. In a cross-section along a plane perpendicular to the axis of the through
hole, the leading edge of the knife has a convex, concave or linear form.

In case of the linear tools, if there is a contact of the material with the tool, the material slips along the leading edge, what decreases the crushing effect. Further, the crushed material is heated up by friction against the leading edge. The material crushing effect is very low. By crushing of elastic materials (tyre rubber, cable rubber, plastics) at normal temperatures without freezing the energy consumption increases, the crushing segments wear down, the material is crushed to such particle size that separation to individual components (metallic wire, textile fibres and rubber) is nearly impossible and economically ineffective. To boost the effect various cryogenic methods are used, which methods comprise freezing of the material so that the material becomes brittle. Thereafter, by rubbing of the material against the tool and by rubbing the material together, the material is rapidly heated up and the required brittleness is lost, whereby, the crushing effectiveness is decreased significantly.

The above-mentioned disadvantages do not appear in case of tools with convex or concave leading edge, but in the crushing process their disadvantage is that their curvature form is not optimal.

According to the invention this problem is solved as follows.

The crushing knife 1 for crushing of material in a chamber (Fig. 1) comprises a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor. In a cross-section along a plane perpendicular
to the axis of the through hole, the leading edge 2 of the knife 1 has a convex form, which convex form is formed by a part of logarithmic spiral. The form can be also formed by a part of Archimedes' spiral or by a part of a circle evolvent.

The crushing knife 1 for crushing of material in a chamber (Fig. 2) comprises a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor. In a cross-section along a plane perpendicular to the axis of the through hole, the leading edge 2 of the knife 1 has a concave form, which concave form is formed by a part of Archimedes' spiral. The form can be also formed by a part of logarithmic spiral or by a part of a circle evolvent.

The above-mentioned forms provide the knife with an optimal form necessary to provide higher crushing effect of the material in case of direct contact of the material with the knife.

Novel forms of knives, individually or in combination of the knives in a system of knives, remove the effect of material slipping and material friction along a linear tool. Therefore, the crushing effect is fully utilized in direct contact of the tool with the crushed material and energy is saved significantly. Consequently, high effect of crushing is obtained. If the curved slats are used, the temperatures are decreased significantly - the crushing effect is severalfold higher and the necessary energy input for driving of the rotating tools is lower in the order of several tenths of percents. Use of the curved tools provides high effectiveness of the crushing process in practice. As a result severalfold finer granularity is obtained (in case of elastic materials!) at the
same level of energy consumption. A result of the decreased energy consumption and the decreased friction share is a significantly lower warming up of the material and the tool. This allows continual crushing or elastic materials.
Claims

1. Method of recycling tyres or other discarded rubber products, so as of conveyor belts, characterised in that the tyres supplied are sorted and checked, then, the tyres are separated into beads (5) with wire beads, sidewalls (4) and tread (3) by water jet in the first stage, the separated sidewalls (4) and tread (3) are separately conveyed to the second stage of cutting by water jet to pieces of uniform size, the cut pieces are frozen, then crushed to a mixture of structure with fully separated individual fractions, the mixture is left to settle down and is then sorted to individual fractions, i.e. textile lint, metal, rubber granulate, and eventually, the finest textile fluff is removed from the final granulate.

2. Method of Claim 1 characterised in that the freezing is carried out continually in a freezing chamber with a charge of liquid nitrogen whilst controlling a stable liquid nitrogen level height in the chamber.

3. Method of Claim 1 or 2 characterised in that crushing is carried out in a destruction chamber by charging cut frozen pieces and crushing them.

4. Method of any of Claims 1 to 3 characterised in that to slow down the flow, the crushed mixture of fractions is blown out of the destruction chamber into a settling chamber, which setting chamber is having the volume corresponding to the output of the destruction chamber, to slow down the flow
of the blown out mixture to a velocity required to settle down fractions of the mixture and the air blown out is further led via a cyclone and an exhaust filter, where the finest particles of rubber and textile lint are captured.

5. Method of Claim 4 characterised in that rough lint is separated from wires and rubber on sieves with mesh size 10 to 12 mm.

6. Method of Claim 5 characterised in that steel wires are separated electromagnetically.

7. Method of Claim 4 characterised in that the rubber granulate is sorted to fractions according to particle size as required.

8. Method of Claim 7 characterised in that the finest textile fluff is separated from the final rubber granulate in separation equipment, preferably of the fluid plate design.

9. Equipment for recycling of discarded rubber products to carry out the method according to anyone of the preceding Claims comprising a freezing chamber and a storage tank for liquid nitrogen characterized in that it comprises a device for controlling of liquid nitrogen level height in the controlling chamber, which controlling chamber is interconnected with the freezing chamber on the principle of interconnected vessels, where the controlling chamber is provided with liquid nitrogen level height sensors, which sensors are connected to an electromagnetic valve of a liquid
nitrogen storage tank for opening/closing input of nitrogen into the controlling chamber.

10. Crushing knife for crushing of material in a chamber for the equipment of Claim 9 comprising a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor and in a cross-section along a plane perpendicular to the axis of the through hole the leading edge (2) of the knife (1) has a convex form, characterized in that the convex form of the leading edge (2) is formed by a part of logarithmic spiral or Archimedes' spiral or by a part of a circle evolvent.

11. Crushing knife for crushing of material in a chamber for the equipment of Claim 9 comprising a longitudinal slat, which slat is provided with a through hole on one end, which hole is used to mount the slat in a rotor, and in a cross-section along a plane perpendicular to the axis of the through hole the leading edge (2) of the knife (1) has a concave form, characterized in that the concave form of the leading edge (2) is formed by a part of logarithmic spiral or Archimedes' spiral or by a part of a circle evolvent.