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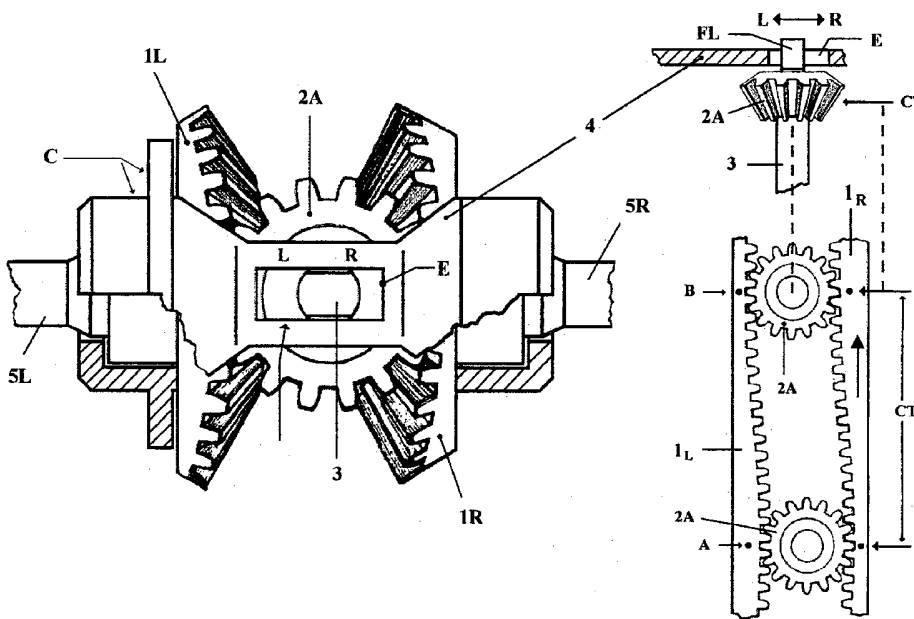
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(54) Title: UNDULATED TOOTHED GEAR



(57) Abstract: This invention concerns a toothed gear with teeth generated from an axially undulated curve. The root circle of the toothed gear is also an undulated curve, parallel to the pitch curve. In a more general case, an undulated toothed gear can also be generated from an undulated open curve. The undulation of the pitch curve results in generating teeth of the undulated gear inclined with respect to the rotation axis of this gear.

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## UNDULATED TOOTHED GEAR

## Subject of the invention

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This invention concerns a differential mechanism consisting of planet-gears with teeth generated not from a pitch circle but from an axially undulated curve; this curve is projected as a circle on a plane perpendicular to its rotation axis. The root circle of the planet-gears is also an undulated curve, parallel to the pitch curve (in a more general case, an undulated gear can also be generated from an undulated open curve and can be used in special rack and pinion mechanisms transforming a rotation motion in a two directional translation motion and in other cases). The undulation of the pitch curve results in generating teeth of the planet-gears inclined with respect to the rotation axis of these gears. The planet-gears of this differential mechanism are engaged with satellite-gears similar to those used in conventional differential mechanisms. However, because of the undulated form of the root circle of the planet-gears, the differential cross pin of the satellites has a reciprocating motion in a slot provided in the differential case for this purpose. The great advantage of the proposed new differential mechanism is that, by controlling the reciprocating motion of the differential cross pin of the satellite-gears, the differentiation of the differential mechanism can be controlled. The invented differential mechanism can be used in a number of applications, for example as a differential for ground vehicles, in the continuous variable transmission, for the activation of opposite piston pumps, e.g.

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## 25 Previous Technical Levels

The conventional bevel gear differential mechanism is a mechanism mainly used in the ground vehicle power transmission system as well as in other applications, in order to fulfil the following tasks: a) Ensure distribution of the driving torque to the output shafts and consequently to the driving wheels. b) Ensure different rotational speeds of the driving wheels, when a vehicle negotiates a turn, travels on uneven road and in other cases.

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## The disadvantage of the conventional differential mechanism

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The disadvantage of the conventional differential mechanism, when used as differential for ground vehicles, is that no more traction can be developed on the driving wheel with the highest adherence coefficient than the traction developed on the driving wheel with the lowest adherence coefficient. If one driving wheel slips on a road of very low adherence coefficient, there is no traction force at all to move the vehicle, because none of the driving wheels can accept higher torque than the torque received by the driving wheel with the lowest adherence. Various attempts have been made in the past to correct this feature by introducing what is known as "non-slip" and "limited-slip" differentials.

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The new differential mechanism proposed in this invention, is a differential mechanism that does not present the disadvantage of the conventional bevel gear differential, is simpler than existing non-slip and limited-slip differentials and provides a very simple mean to control the differentiation and consequently to control the slip of the wheels.

## Brief description of figures

5 Six figures are used to describe the invention. Figure -1- is a plane view of the two planet-gears (1L) and (1R) with the undulated root circle, engaged with the conventional concentric satellites (2A) and (2B) supported by the satellites pin (differential cross pin) (3).

10 Figure -2- depicts a satellite (2A) without its differential cross pin, while figure -3- is a cross section of the differential case (4) perpendicular to the driving pinion axis.

Figure -4- is a top view of the differential case (4) figuring one of the two edges of the satellites' differential cross pin (3) as well as the slots (E) of the differential case, within which this pin can have a reciprocating motion from the left to the right.

15 Figure -5- is a cross section of the planets (1L) and (1R) bringing in evidence the curved form of their teathed surface (CT), as well as the displacement of one of the satellites between the planets.

20 Figure -6- gives schematically an example of a system that can be used in order to control the reciprocating motion of the differential cross pin (3) and thus control the differentiation of the mechanism. This control system consists of a reciprocating object – bar (6) between the side (FL) of the differential cross pin (3) and one of the slot's sides (E). The principle of the control system is the application of a force proportional to the desired effect on the edge of the satellites' differential cross pin (3) that moves in  
25 the slot of the differential case.

## Description of the Invention

30 The proposed Differential Mechanism consists of two planets (1L) and (1R) of the innovative form described here after, having the same rotation axis, facing each other and are positioned in a distance such that two or more bevel gears, the satellites (2A) and (2B), can be mounted between them in order to continuously and harmonically engage with them. All these gears are mounted inside the cylindrical differential case (4). Each satellite or group of satellites has a common differential cross pin (3). Each  
35 edge (FL) of this pin abuts in a slot (E) provided in the differential case.

The proposed Differential Mechanism's planets (1L) and (1R) have an innovative form. They are cut not on an even surface of a disk, as it is done for the planets of the conventional differential, but on an undulated surface generated from the intersection of  
40 cylinders. The undulated teathed surface of each planet consists of an adequate number of sections (CT) that are up-slope section and down-slope section, such that there is a continuous change of the height of the teathed gear (planet). The difference in height of the teathed surface of the planet from the up-slope point to the down slope point is (S). The number of the up-slope and down-slope sections of the planets depends on the  
45 number of satellites used on the mechanism, the latter depending on the torque to be distributed. The creation of a distance (S) between the peaks of the teeth of the two planets, as appears in figure -1-, is the reason of the existence of the undulated surface in each planet.

The planets carry in their base adequate splines to receive the splined half-shafts (5L) and (5R) which transmit the rotation motion of the power-group to the driving wheels. The two planets, and consequently the two half shafts, can rotate with the same angular velocity or with different angular velocities (differential rotation).

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The satellites have a complex motion, which is the composition of three simpler motions: a) A rotational motion all together with the differential case around the case's rotation axis. b) A rotational motion around the differential cross pin (3). c) A reciprocating motion perpendicular to the axis of the differential cross pin, initiated by the reciprocating motion of this pin within the slots (E) of the differential case. The reciprocating motion that results from the fluctuation of the undulation height (S) is possible when the angular velocity of one planet with respect to the angular velocity of the other planet is different.

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The technique presented by figure -6- is only one example of the numerous other techniques that can be presented for this purpose. In the proposed technique the velocity that the differential's cross pin reciprocates is a factor that can activate the system of the automatic differential arrestor which depends on the reciprocation of the object – bar (6).

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During the assembly procedure of the proposed Differential Mechanism, the curved planets can be mounted in two possible ways that prescribe the use of this mechanism:

a) When it is desirable to use the differential mechanism as a differential in a ground vehicle, the planets are mounted in such respective position so that the peak point of an up-slope section of one planet coincides with the lower point of a down-slope section of the opposite planet and the distance between them is the required distance to achieve the permanent engagement of the satellites with the planets.

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b) When it is desirable to use the differential mechanism as a two-output-mechanism transforming rotational motion to reciprocating translation motion, the planets are mounted in such respective position so that the peak point of an up-slope section of one planet coincides with the peak point of an up-slope section of the opposite planet. In that case adequate springs or any other appropriate system is used to achieve the permanent engagement of the satellites with the planets.

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c) When it is desirable to transform rotation motion in a two directional translation motion, an undulated gear generated from an open undulated curve can be used.

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### Invention's Operation Principle

When the proposed differential mechanism is used as differential in a ground vehicle and this vehicle is following an absolute straight path, the two planets have the same rotational speed and the proposed differential behaves and operates exactly like the already known conventional differential: the planets rotate all together with the differential case, splitting equally the torque transmitted by the driving pinion to the crown, the latter rotating with the differential case. Hence, motion is transmitted via the driving pinion to the crown; the crown is placed in position (C) of the differential case (4), which is rotated around its axis. The satellites gears (2A) and (2B) do not rotate around themselves, but rotate together with the differential case and, consequently, they equally transmit the rotation to the planets (1L) and (1R), to the half shafts (5L) and (5R) and finally to the wheels. In case the vehicle follows a curvilinear path, or in case that for any other reason, the angular velocity of the driving wheel, of the half-shaft and

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of the planet of one side is required to be different from that of the opposite side of the vehicle, the proposed Differential Mechanism behaves as follows: The power-group's motion is transmitted by the driving pinion and, via the crown, to the differential case, which rotates around its axis. The group of satellites transmits this motion to the planets, but since there is need for a differential rotation of the two wheels and consequently of the two half-shafts and of the two planets, the satellites start rotating around the differential cross pin within the differential case, while this pin is having a reciprocating sliding motion within the slot provided in the differential case for this purpose. As depicted from figure -5-, in case planet (1L) is immobilized while the opposite planet (1R) continuous to rotate, the satellite (2A) will be displaced from point (A) to point (B) on the immobilized planet, driven by the non immobilized planet (1R). The teathed curved track (CT) will impose an horizontal sliding motion to the differential cross pin (3) of the satellites; that will have as a result the reciprocating motion of the edges (FL) of this pin within the slots (E) provided in the differential case (4), once to the left, indicated as -L- in figure -5- and once to the right, indicated as -R- in this figure.

When the proposed differential mechanism is used as a two-output-mechanism transforming rotational motion to reciprocating translation motion, the planets must be mounted in such respective position so that the peak point of an up-slope section of one planet coincides with the peak point of an up-slope section of the opposite planet and the distance between them is the required distance to achieve the permanent engagement of the satellites with the planets; moreover, in that case, adequate springs or any other appropriate system is used to achieve the permanent engagement of the satellites with the planets. Then the two half-shafts will have a reciprocating motion whose useful stroke will be equal to the undulation height (S).

### Advantages of this invention

When used on a ground vehicle as a differential, the advantage of the proposed differential mechanism is that this differential is of controllable differentiation; consequently it is a controllable slip differential.

One of the numerous techniques of controlling the differential's differentiation is illustrated by figure -6- and is that of the cooperation of the reciprocating differential cross pin (3) with a reciprocating object – bar (6) which is activated by the gradual increase of the reciprocation rate of the satellite' differential cross pin (3). The system consists of a bar (6) which carries the cylinder (7). The cylinder's side does not abut on the straight section of the slots' side (K), thus the bar (6) can freely reciprocate without any limit. The vector of the bar's (6) reciprocation depends on the velocity of the reciprocation (per unit of time) of the differential cross pin (3)

During the differentiation operation of the differential mechanism, when the vehicle negotiates a long turn, the reciprocation of the differential's cross pin (3) has the maximum amplitude for example (L2) while the distance between the two edges (A1-A2) of the bar (6) will be relatively shorter from the maximum traversed reciprocation (L2) of the differential's cross pin (3)

If the differentiation of the revolutions between the two driving wheels is regular, then the bar (6) is forced by the differential's cross pin to regularly reciprocate while the

cylinder (7) is within the area (K) following the straight section of the edge. If the reciprocation velocity of the differential's cross pin (3) will increase per unit of time (zero torque to the one driving wheel and maximum torque to the other driving wheel), then the impact of the differential's cross pin on the bar will give to the bar such amount of kinetic energy that the cylinder (7) will traverse the straight section (K) and the bar will stop this displacement as soon as the cylinder reaches the beginning of the inclined surface (I), and while the differential's cross pin (3) is moving (with the same direction) towards the completion of its reciprocation, owing to the existence of the inclined surface, an automatic engagement will be caused which will in turn cause a partial or a complete arrest of the differentiation of the revolutions.

The control is achieved by application of a force to control or limit the displacement rate of the edges (FL) of the satellites differential cross pin (3) that has a reciprocating translation motion in the slot (E) of the differential case. Any classic control system, mechanical-hydraulic-pneumatic-electric-electronic can be used to apply a proportional force; also, a more sophisticated control algorithm can also be used. An intervention at the point where the differentiation is generated, presents the advantage that the magnitude of the required control force is lower than in other systems available on the market. The controllable differentiation operation, compared to the absolute free differentiation operation, prevents spinning of the half-shafts and consequently prevents the endless and uncontrolled rotation of the driving wheel that has lost grip on the ground, which leads to loss of power and to vehicle's immobilization.

When used as a two-output-mechanism transforming rotational motion to reciprocating translation motion, the advantage of the proposed mechanism is that it has two outputs, permitting to be used e.g. for the operation of two double stroke pumps and in many other cases, and the advantage that the motion transformation rate of this mechanism can be controlled by a control system similar to the one described in the previous paragraph.

When used a special rack and pinion mechanism, the advantage of the proposed undulated rack is that it transforms the rotation motion of the pinion in a two directional translation motion.

## CLAIMS

1. A toothed gear characterised by the following: a) The teeth are generated not from a pitch circle as is done with conventional toothed gears, but from a pitch curve that is an axially undulated curve such that its projection on a plane perpendicular to the rotation axis of the gear is a circle. b) The root curve of the gear is also an undulated curve, parallel to the pitch curve. c) The undulation of the pitch curve results in generating teeth of the planet-gears inclined with respect to the rotation axis of this gear. d) The teeth of the proposed gear are cut not on an even surface, as it is done for conventional toothed gears, but on an undulated surface generated from the intersection of cylinders such that the undulated toothed surface of each gear consists of an adequate number of sections (CT) that are up-slope sections and down-slope sections, such that there is a continuous change of the height of the toothed gear, the difference in height of the toothed surface of the gear from the up-slope point to the down slope point being (S) and the number of the up-slope and down-slope sections of the gear depending on the specific application in which these gears will be used, e.g. as planets for the proposed differential mechanism and in many other applications.
2. A toothed gear characterised by the following: a) The teeth are generated from a pitch curve that is an axially undulated open curve such that its projection on a plane perpendicular to the rotation axis of the gear is an open line. b) The root curve of the gear is also an undulated curve, parallel to the pitch curve. c) The undulation of the pitch curve results in generating teeth of the toothed gear inclined with respect to the rotation axis of this gear. d) The teeth of the proposed gear (rack) are cut not on an even surface, as it is done for conventional toothed gears, but on an undulated surface generated from the intersection of cylinders such that the undulated toothed surface of each gear (rack) consists of an adequate number of sections that are up-slope sections and down-slope sections, such that there is a continuous change of the height of the toothed gear (rack), the difference in height of the toothed surface of the gear (rack) from the peak point of an up-slope section to the lower point of a down-slope section being (S) and the number of the up-slope and down-slope sections of the gear depending on the specific application in which these gears will be used. This gear can be used in mechanisms transforming a rotational motion in a two directional translation motion e.g. special rack and pinion mechanisms, and in many other applications.
3. A controllable differentiation differential mechanism with undulated planet-gears consisting of two planet-gears (1L) and (1R) as described in claim -1-, of two or more satellites (2A) and (2B), of a differential case (4) inside which are mounted all the planet and satellite-gears - the case receiving the motion of a power group by a pinion and a crown or by any other adequate system - and of two half-shafts mounted via splines or by any other adequate system to the two planets, and which mechanism is characterised by the following: a) The toothed planet-gears (1L) and (1R) used are as described in claim -1-, that is they are cut on an undulated surface generated by the intersection of cylinders of appropriate diameter, such that the above mentioned undulated surface of the planets is formed by an appropriate number of up-slope sections and down-slope sections (CT), which achieve the variation of the position of every toothed gear engaged with these planets. b) The peak point of an up-slope section of the toothed surface of one planet coincides with the lower point of down-slope section of the toothed surface of the opposite planet, such that the distance between the planet-gears is such that two or more satellite-

- gears (2A) and (2B) are continually and uninterruptedly engaged with the planets rolling between the undulated surfaces of the planets. c) The satellites are mounted inside the differential case (4) in a way that they can rotate with the case and, moreover, each satellite can rotate around its differential cross pin (3) and can also have a reciprocating translation motion while rolling on the up-slope sections and down-slope sections of the undulated and teathed surface of the planets.
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4. A differential case (4) having slots (E) to maintain the edges (FL) of the differential cross pin of each satellite or group of satellites, characterised by the following: a) The reciprocation motion of each edge (FL) within the slots (E) is allowed, while these edges follow the planets' waveform motion. b) The slots on the differential case operate as guides in order to maintain the possibility of rotation of the differential cross pin of each satellite or group of satellites together with the differential case of this differential mechanism. c) The satellites' reciprocating motion can be controlled by a system that limits the free translation motion of the differential pin of the satellites that are mounted between and in continuous engagement with the undulated surface of the planets, while they follow the up-slope sections and down-slope of the undulated teathed surface of the planets. d) The control mechanism is such that it controls the differentiation of the shafts' rotation and hence the planets' rotation, by application of a deceleration force controlling and limiting the reciprocating motion, and consequently limiting the transmission of power and torque - via the differential case (4) and the satellites (2A) and (2B) - towards the immobilized planet.
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5. A controllable differentiation differential mechanism with undulated planet-gears consisting of two planet-gears (1L) and (1R) as described in claim -1-, of two or more satellites (2A) and (2B), of a differential case (4) inside which are mounted all the planet and satellite-gears - the case receiving the motion of a power group by a pinion and a crown or by any other adequate system - and of two half-shafts mounted via splines or by any other adequate system to the two planets, and which mechanism is characterised by the following: a) The teathed planet-gears (1L) and (1R) used are as described in claim -1-, that is they are cut on an undulated surface generated by the intersection of cylinders of appropriate diameter, such that the above mentioned undulated surface of the planets is formed by an appropriate number of up-slope sections and down-slope sections (CT), which achieve the variation of the position of every teathed gear engaged with these planets. b) The peak point of an up-slope section of the teathed surface of one planet coincides with the peak point of up-slope section of the teathed surface of the opposite planet, such that the distance between the planet-gears is such that two or more satellite-gears (2A) and (2B) are continually and uninterruptedly engaged with the planets rolling between the undulated surfaces of the planets. c) The satellite-gears are mounted inside the differential case (4) in a way that they can rotate with the case and, moreover, each satellite can rotate around its differential cross pin (3) and can also have a reciprocating translation motion while rolling on the up-slope sections and down-slope sections of the undulated and teathed surface of the planets, such that this system achieves the transformation of the rotation motion of the differential case in a reciprocate translation motion of the output half-shafts and such that it can be used e.g. for the operation of two double stroke pumps and in many other applications. d) Adequate springs or any other appropriate system is used to achieve the permanent engagement of the satellites with the planets assuring that the two half-shafts have a reciprocate motion whose useful half-stroke is equal to the undulation height (S).
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FIG 1

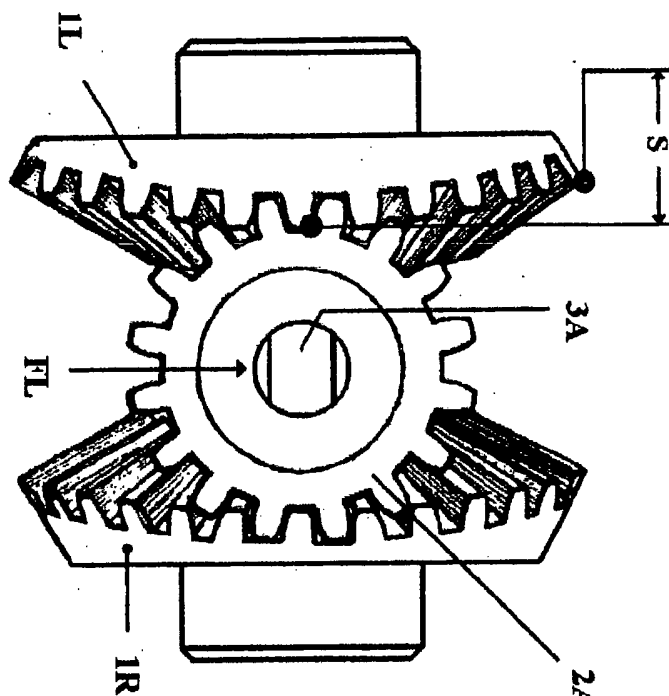


FIG 2

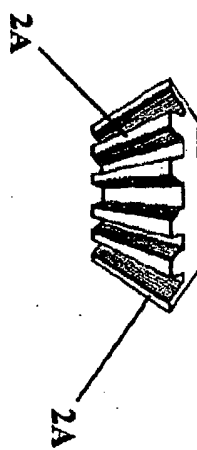
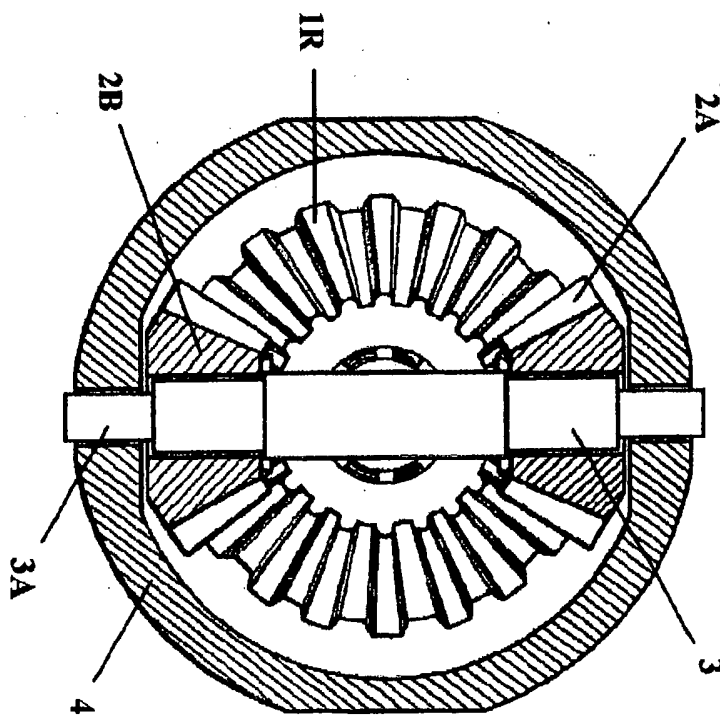


FIG 3





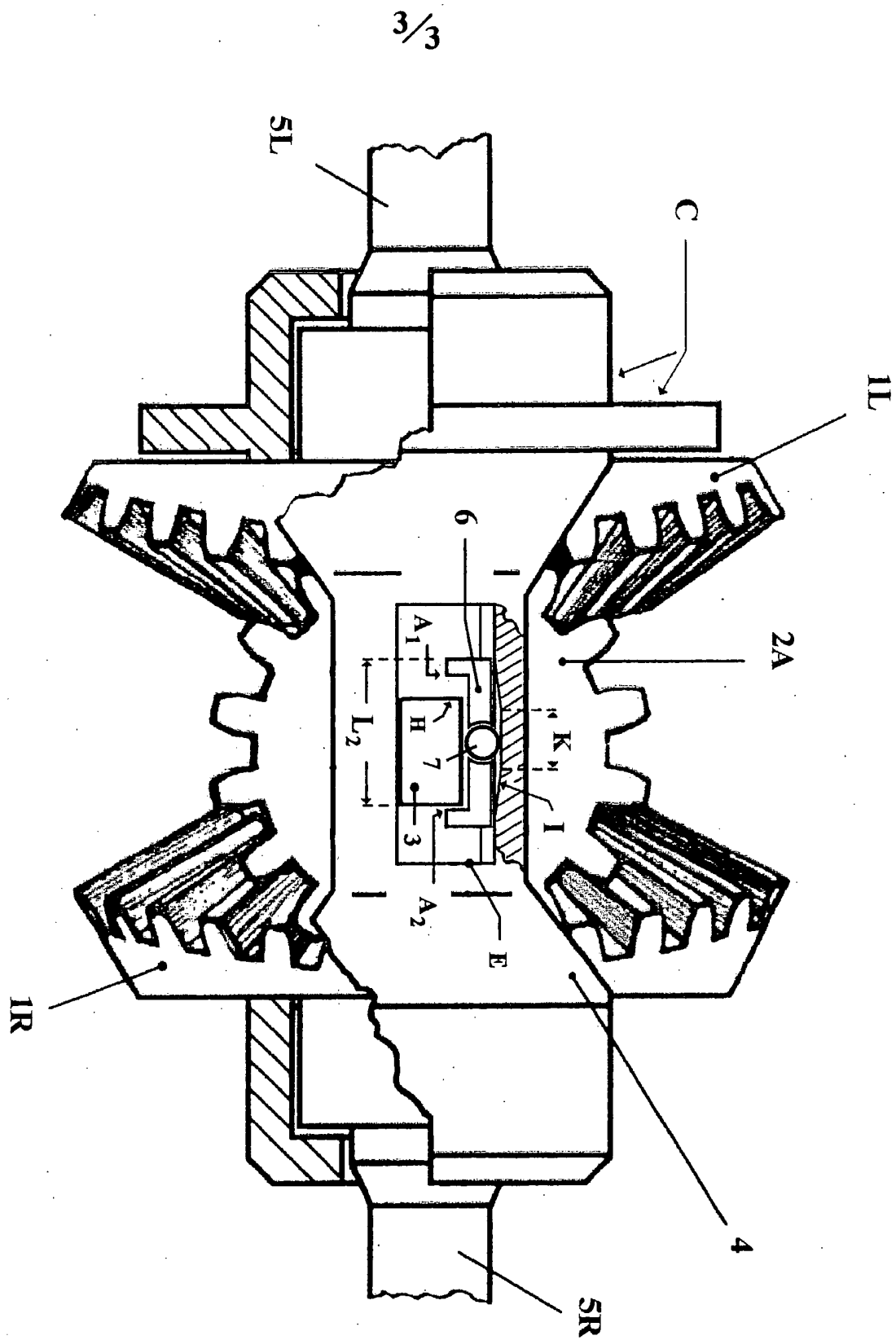


FIG 6

# INTERNATIONAL SEARCH REPORT

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<b>A. CLASSIFICATION OF SUBJECT MATTER</b> F16H55/17      F16H48/06      F16H48/20				
According to International Patent Classification (IPC) or to both national classification and IPC				
<b>B. FIELDS SEARCHED</b>				
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched				
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, PAJ				
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>				
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.		
A	FR 2 547 883 A (BOSSUET CLAUDE) 28 December 1984 (1984-12-28) figure 1 -----	1-5		
A	EP 1 288 419 A (GEZE GMBH) 5 March 2003 (2003-03-05) the whole document -----	1		
A	GB 1 011 752 A (DANA CORPORATION) 1 December 1965 (1965-12-01) figures 1-3 -----	4		
A	US 2004/162178 A1 (KRZESICKI RICHARD M ET AL) 19 August 2004 (2004-08-19) figures 1-8 -----	4		
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 197 11 015 A1 (BORG-WARNER AUTOMOTIVE, INC., STERLING HEIGHTS, MICH., US) 30 October 1997 (1997-10-30) figures 6-8 -----	4
A	WO 2004/053357 A (RONJO COMPANY, LLC) 24 June 2004 (2004-06-24) figures 1-4 -----	4

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/GR2005/000028

## Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
  
2.  Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
  
3.  Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1.  As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
  
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
  
3.  As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
  
4.  No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

### Remark on Protest

- The additional search fees were accompanied by the applicant's protest.
- No protest accompanied the payment of additional search fees.

**FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210**

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-3,5

A toothed gear with an axially undulated curve.

1.1. claims: 1,3,5

A toothed gear with an axially undulated pitch curve.

1.2. claim: 2

A toothed gear with an axially undulated open curve.

2. claim: 4

A differential case.

## INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GR2005/000028

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