(12) UK Patent Application (19) GB (11) 2 429 779 (13) A

(43) Date of A Publication 07.03.2007

(21) Application No: 0517844.7

(22) Date of Filing: 01.09.2005

(71) Applicant(s):
Geo. Kingsbury Machine Tools Limited
(Incorporated in the United Kingdom)
Quay Lane, Hardway, GOSPORT,
Hampshire, PO12 4LB, United Kingdom

(72) Inventor(s):
Richard G Kingsbury
William Coleman

(74) Agent and/or Address for Service:
D Young & Co
120 Holborn, LONDON, EC1N 2DY,
United Kingdom

(51) INT CL:
G01M 13/02 (2006.01)

(52) UK CL (Edition X):
G1J J30
G1W WE4TX

(56) Documents Cited:
GB 2391071 A **GB 2111355 A**
JP 070012683 A **SU 000524991 A**
US 20050081644 A

(58) Field of Search:
UK CL (Edition X) **B7H, G1J, G1W**
INT CL **G01M**
Other: **Online: The Internet, English language full text databases, WPI & EPODOC**

(54) Abstract Title**: Testing components of drive trains**

(57) A drive line B’ for testing a component D, preferably a vehicle differential, of a drive train comprises a torque sensor BT which is mounted between a spindle assembly and an intermediate bearing of the line B’. The torque sensor measures AC variations in torque due to the operation of the component D. The component D is coupled to the driveline by an uninstrumented adaptor B6’. In alternative embodiments the input adaptor my have a torque sensor for sensing AC vibrations and the output adaptor(s) are uninstrumented. Alternatively the drive line is characterised by having a quiescent zone (Z) is in the gear mesh frequency range 350Hz < Z ≤ 1000Hz or more.

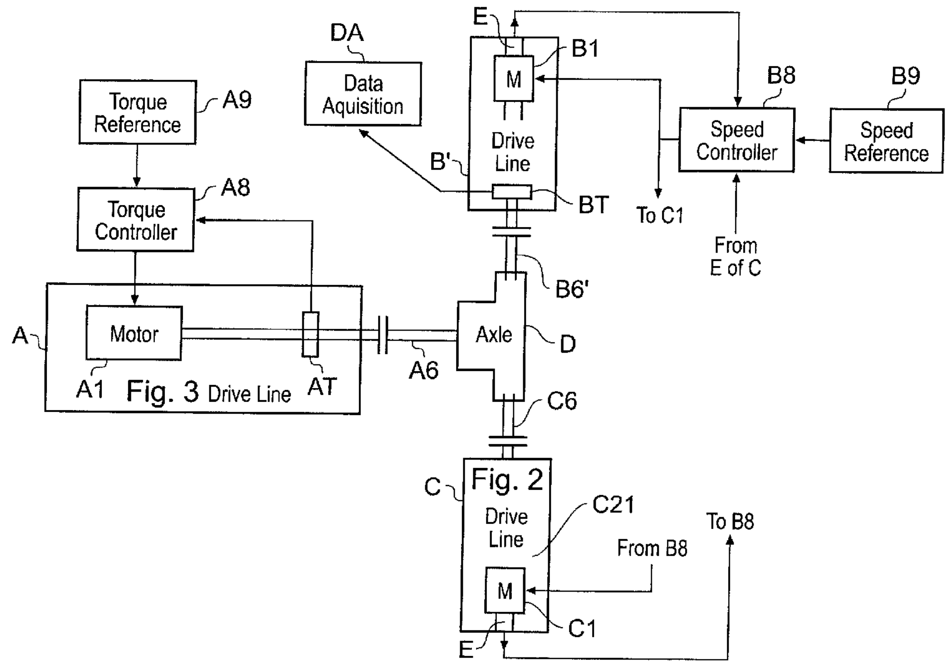


Fig. 5

GB 2 429 779 A

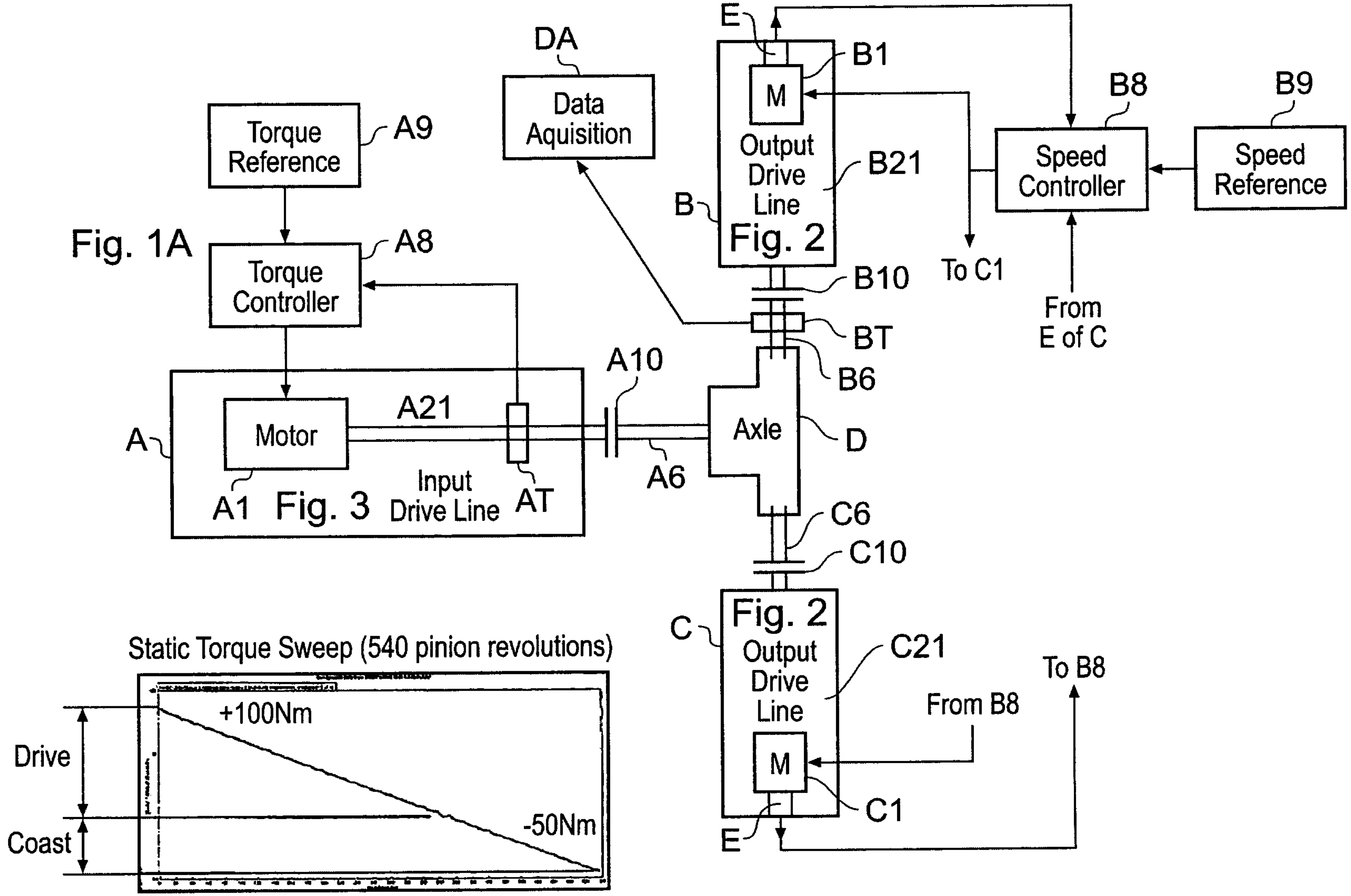

Torque Reference
A9
Torque Controller
A8
Motor
A1
A21
AT
Input Drive Line
Fig. 3
A
A10
A6
Data Aquisition
DA
E
M
B1
Output Drive Line
B21
B
Fig. 2
B10
BT
B6
Axle
D
C6
C10
Fig. 2
Output Drive Line
C21
C
M
C1
E
Speed Controller
B8
Speed Reference
B9
To C1
From E of C
From B8
To B8
Static Torque Sweep (540 pinion revolutions)
+100Nm
-50Nm
Drive
Coast

Fig. 1A

Fig. 1B

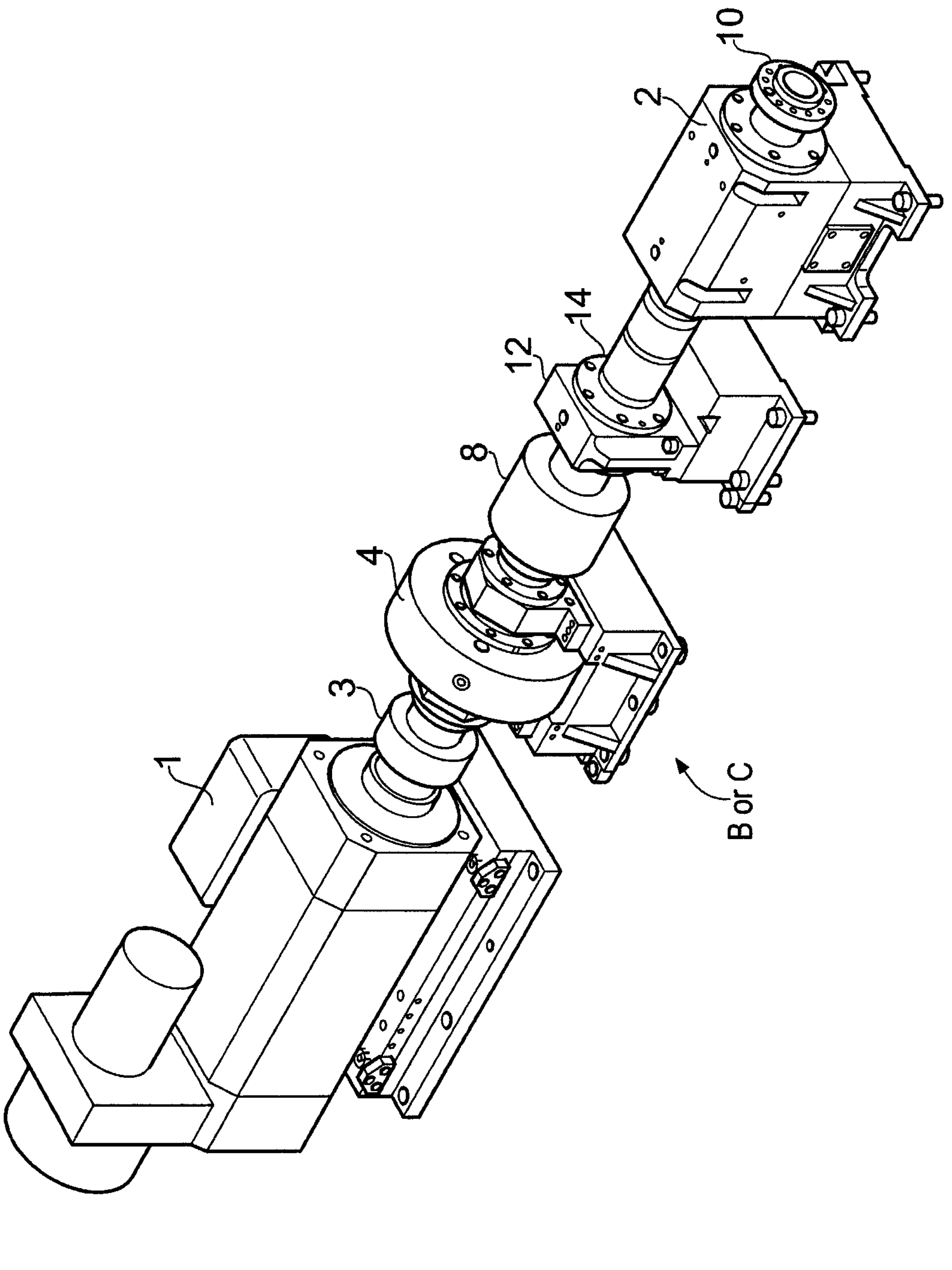


Fig. 2

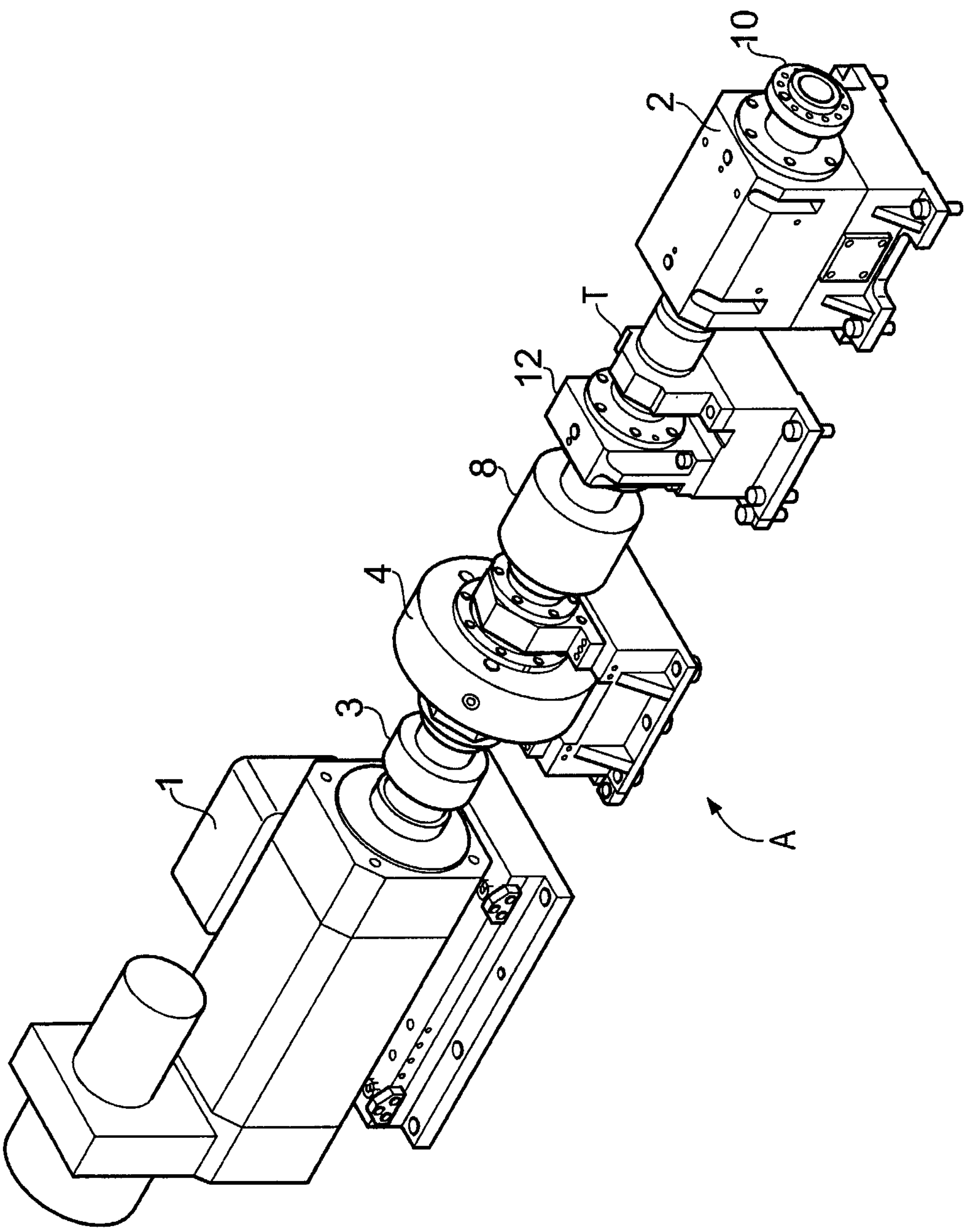


Fig. 3

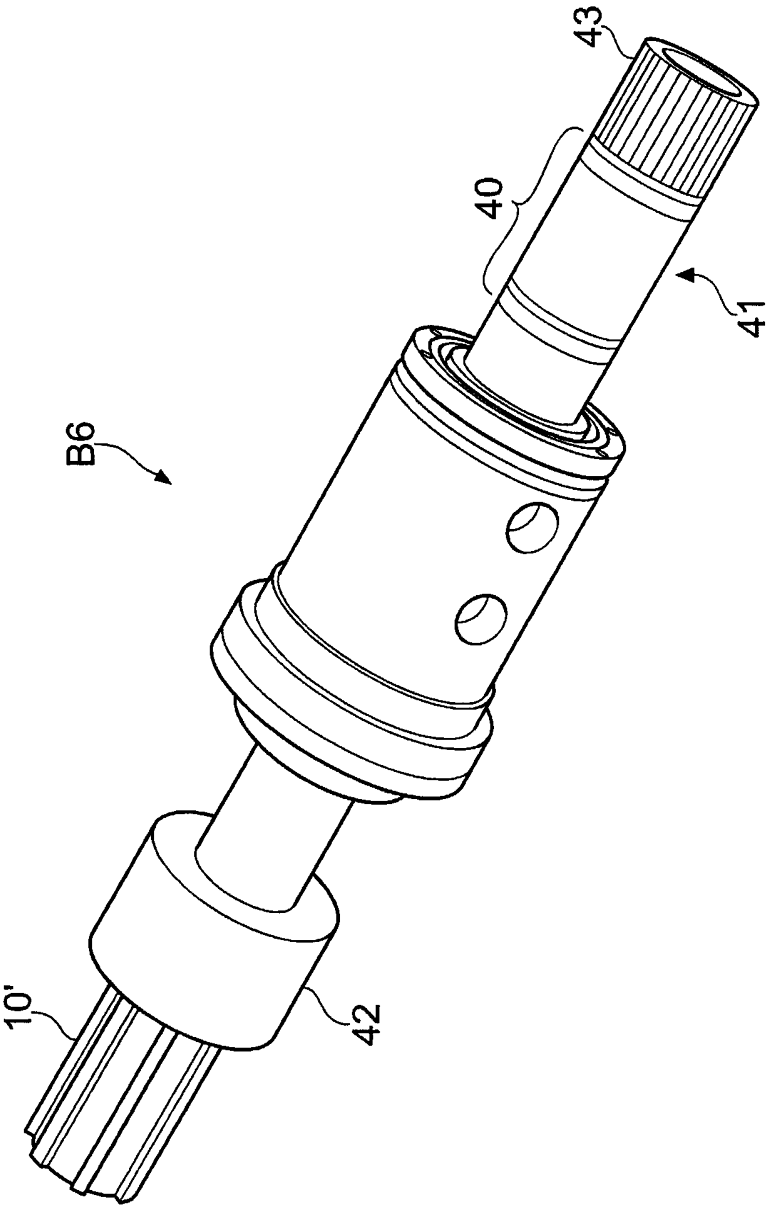


Fig. 4

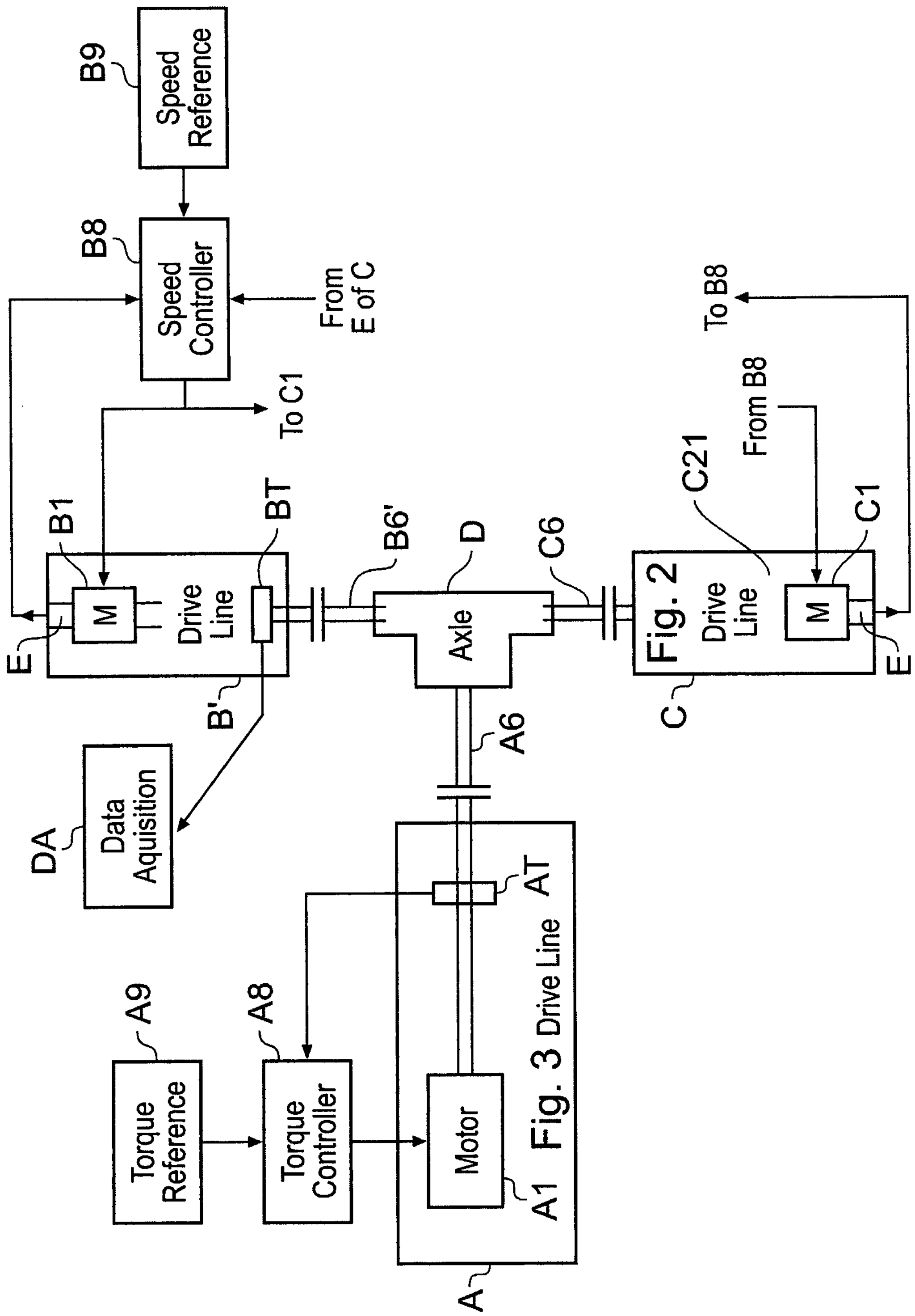

Speed Reference
B9
Speed Controller
B8
From E of C
To C1
B1
M
E
Drive Line
BT
B'
Data Aquisition
DA
B6'
D
Axle
C6
A6
C21
From B8
To B8
C1
Fig. 2
Drive Line
M
E
C
AT
Fig. 3 Drive Line
Torque Reference
A9
Torque Controller
A8
Motor
A1
A

Fig. 5

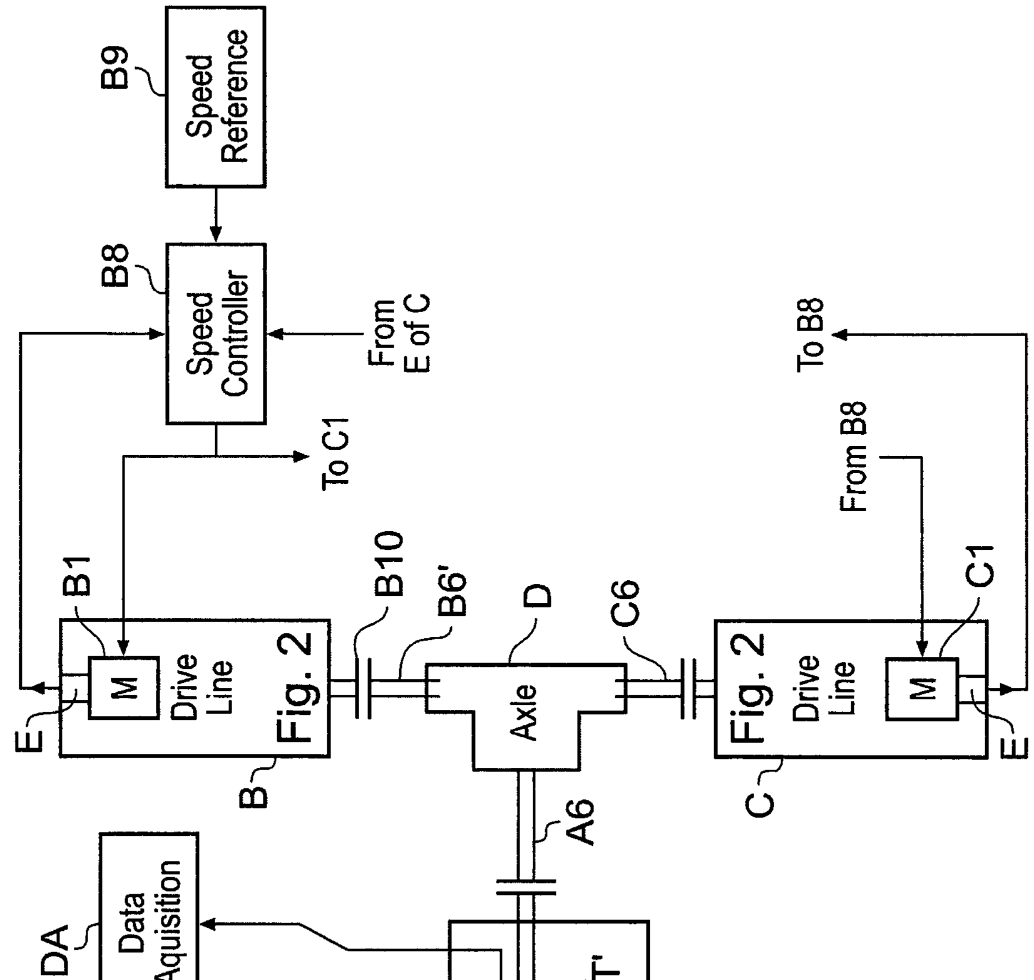

Speed Reference
B9
Speed Controller
B8
From E of C
To C1
B1
M
Drive Line
Fig. 2
E
B
B10
B6'
D
Axle
C6
Fig. 2
Drive Line
M
C1
From B8
To B8
E
C
A6
Data Aquisition
DA
AT'
Drive Line
Torque Reference
A9
Torque Controller
A8
Motor
A1
A'

Fig. 6A

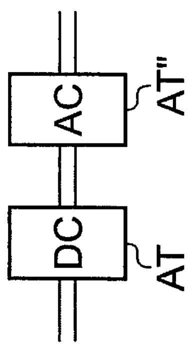
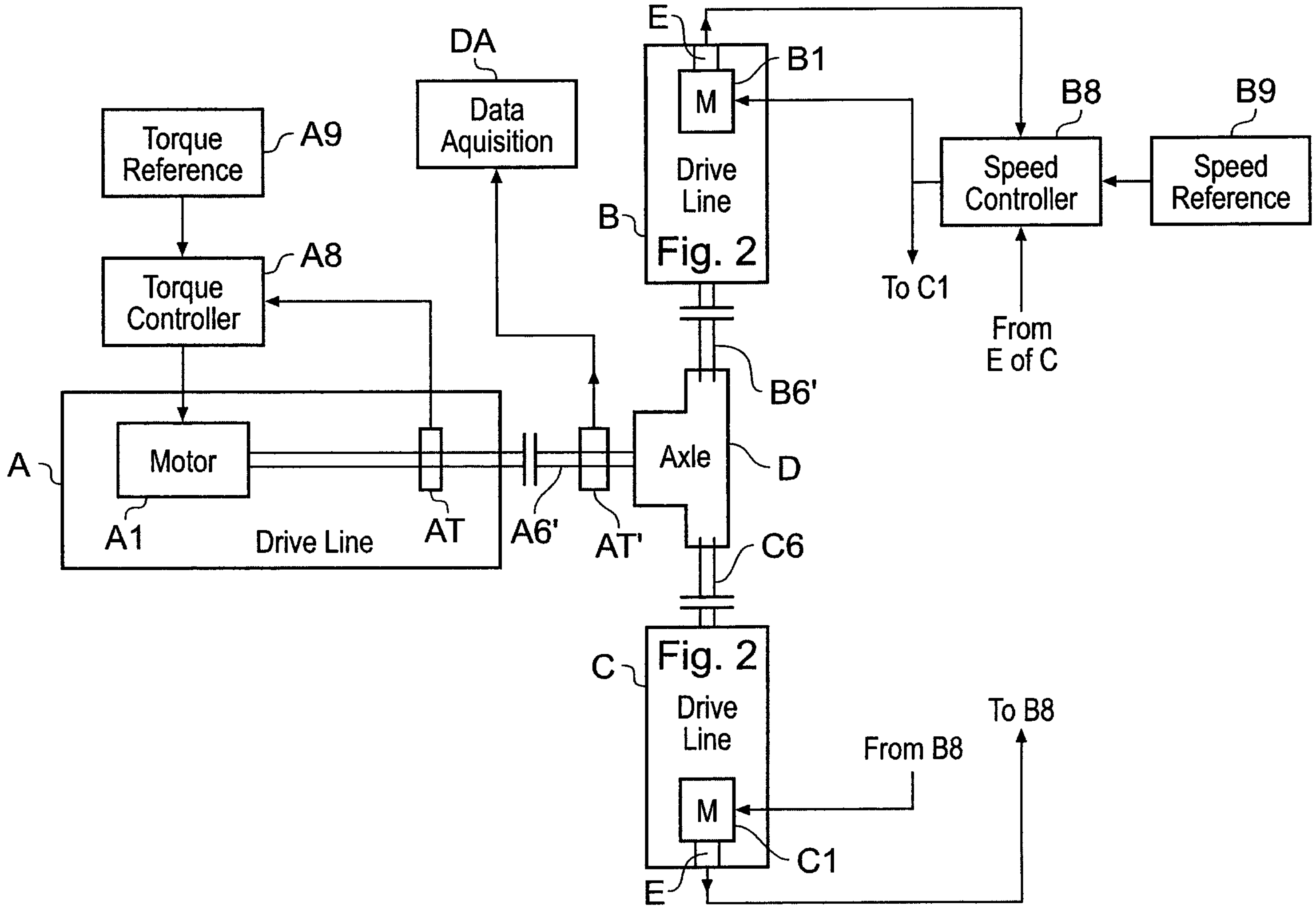

DC
AC
AT
AT"

Fig. 6B



Torque Reference
A9
Torque Controller
A8
Data Aquisition
DA
E
B1
M
Drive Line
B
Fig. 2
B8
Speed Controller
B9
Speed Reference
To C1
From E of C
B6'
A
Motor
A1
Drive Line
AT
A6'
AT'
Axle
D
C6
C
Fig. 2
Drive Line
M
C1
E
From B8
To B8

Fig. 7

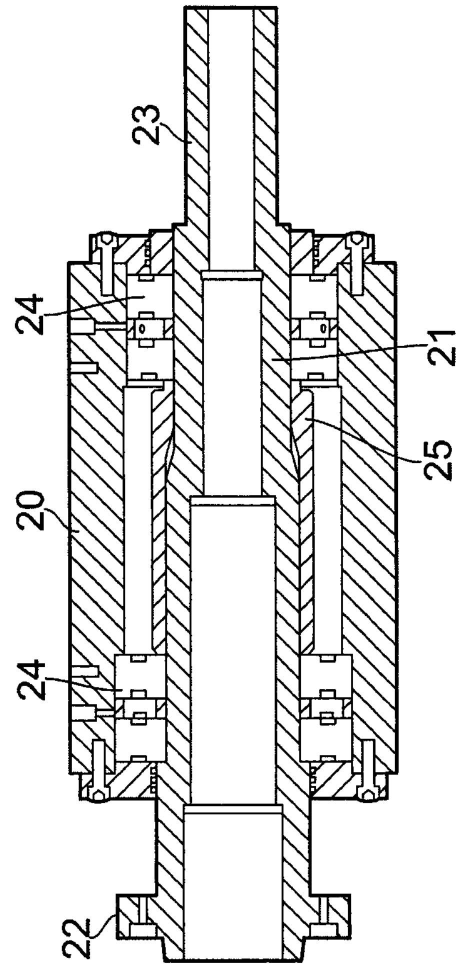


Fig. 8

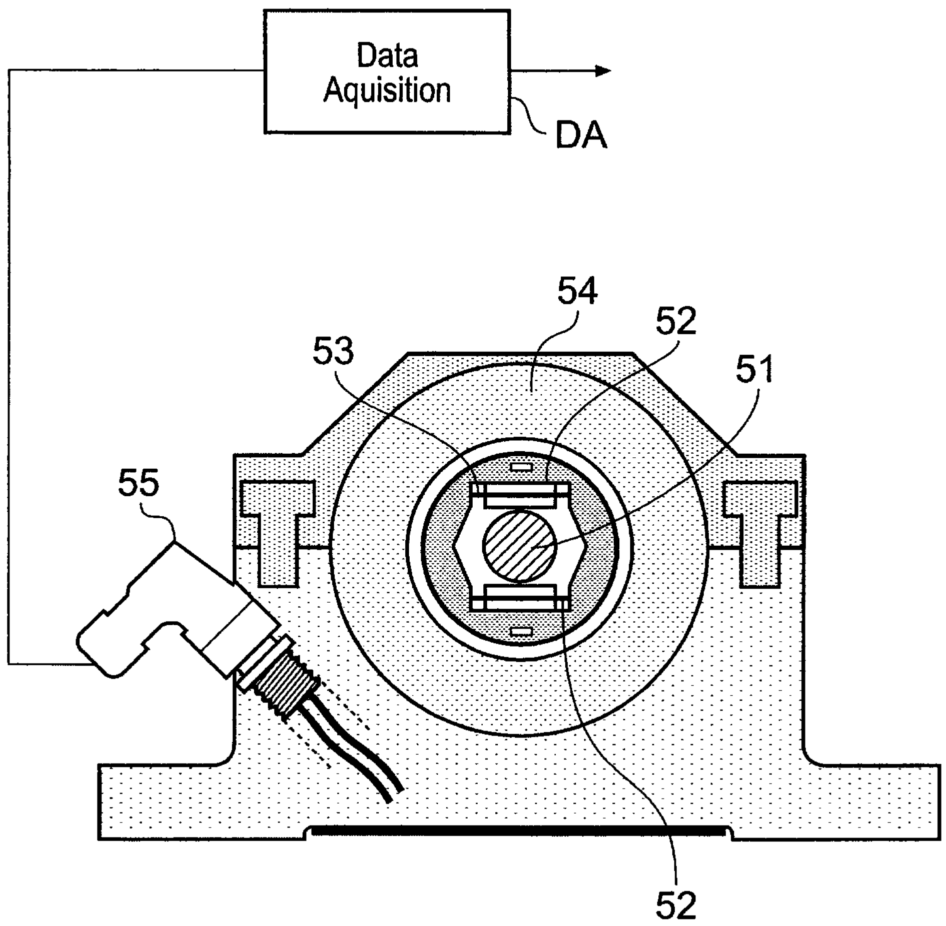


Fig. 9A

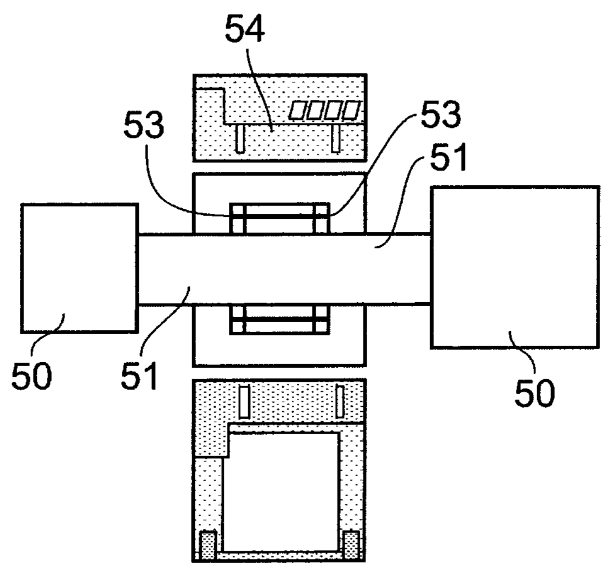


Fig. 9B

30 11 05

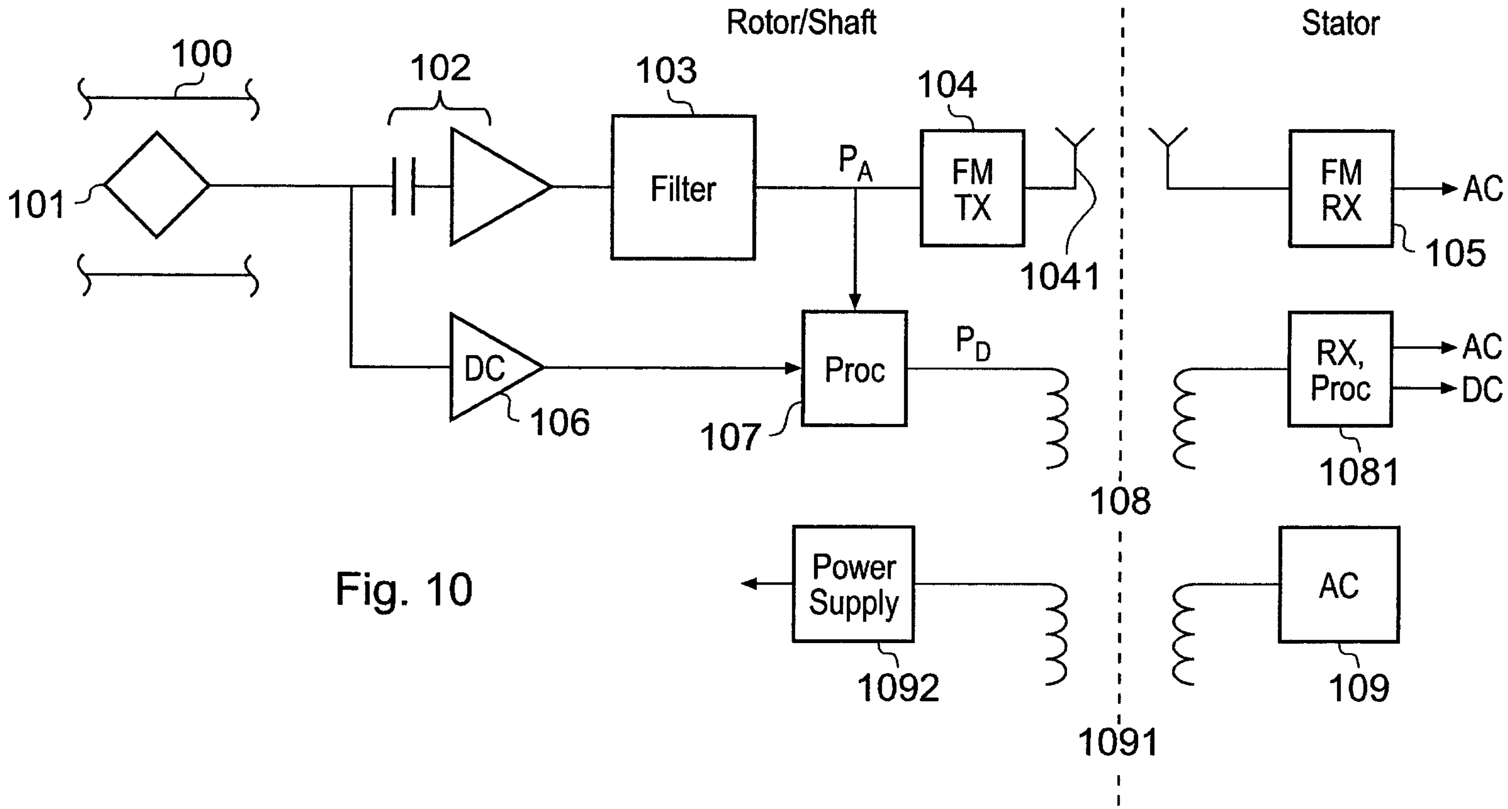


Fig. 10

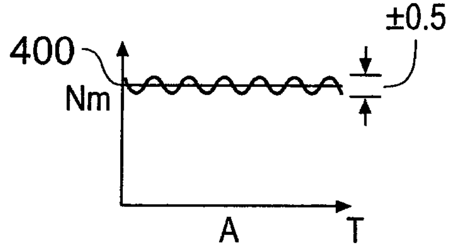


Fig. 11

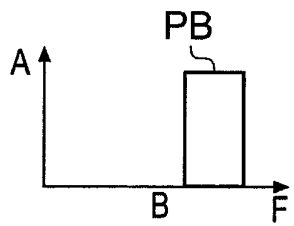


Fig. 12

Testing Components of Drive Trains

The present invention relates to apparatus for, and a method of, testing a component of a drive train of a vehicle. In the following an example of such a component is an axle including a differential gear assembly but the invention could be applied to other components for example a gear box, or a transfer box of a four wheel drive, amongst other examples.

It is known to use a test apparatus for NVH testing of drive train components where NVH indicates Noise, Vibration and Harshness. The testing also tests that the component is functional; e.g. the elements of the component such as gears and bearings are not jammed. Various NVH testing techniques have been proposed. In one technique an array of microphones is used to monitor noise output whilst the component is driven by for example an electric motor which also tests the functionality of the component. Another technique uses accelerometers to detect vibration. Another uses a laser vibration detector. Each of these techniques provide results of varying reliability and repeatability.

A technique used by the present Applicants since about July 2004 will now be described by way of example to the accompanying Figures 1, 2, 3 and 4 in which:

Figure 1A is a simplified schematic plan view of a known test apparatus;

Figure 1B is a graph showing a variation in static (DC) torque;

Figure 2 is a perspective view of an output drive line of the apparatus of Figure 1;

Figure 3 is a perspective view of an input drive line of the apparatus of Figure 1; and

Figure 4 is a view of an instrumented adapter used with one of the output drive lines of Figure1.

Referring to Figure 1, the test apparatus comprises 3 drive lines A, B and C of which drive line A is an input drive line and lines B and C are output drive lines. An example of the output drive line is shown in Figure 2. An example of the input drive line is shown in Figure 3. Each drive line comprises a motor A1, B1 , C1 coupled by other drive line components A21, B21, C21 (illustrated schematically) forming a shaft arrangement to component D under test via an adapter A6, B6 and C6. The adapters connect the drive lines to respective shafts of the component D. The component under test in this example is an axle of a vehicle. Drive line A mimics the engine of a vehicle and drive lines B and C mimic the rear wheels of the vehicle. Adapter B6 is instrumented in that it has a torque sensor BT for detecting AC torque variations on the axle of the component under test. The sensor BT is connected to a data acquisition device DA which records the signal produced by the sensor BT for analysis by a signal processor which is not shown. The adapters A6 and C6 are plain adapters (i.e. they are not instrumented).

Motors B1 and C1 of the output drive lines B and C are controlled to drive the axles of the component under test at a fixed speed whilst a torque which varies in a predetermined manner is applied by the input drive line A to the component under test.

The input drive line A includes a DC torque sensor AT (an example of which will be described in more detail below) on the shaft arrangement A21 of the drive line: i.e. it is not on the adapter A6. The DC torque sensor AT feeds back to a torque controller A8 a measure of the torque applied by the drive line to the component D under test. The controller A8 compares the fed back torque measurement with a reference torque produced by a reference source A9 to control the motor A1. The reference source causes the torque to vary in a predetermined manner and the torque controller 8 cause the torque applied by the drive line A to vary in the predetermined manner to a precise tolerance.

The motors B1 and C1 of the output drive lines B and C are controlled by a speed controller B8 which controls both motors to run at the same speed. Each motor has an encoder E which feeds back to the controller B8 the speed of the motor. The fedback speed information is compared in the speed controller B8 with a speed reference produced by a speed reference source B9 and the motors are controlled accordingly in conventional manner.

Each drive line is mounted on a slide (not shown) to bring the adapter into engagement with a shaft of the axle D. The purpose of the adapters A6, B6, C6 is to provide a member which fits both the drive line and the particular model of axle under test. Different models may require different adapters A6, B6, C6.

In an example of a test procedure in which the component under test is an axle containing a differential, the output motors B1 and C1 of the drive lines B and C drive the output shafts of the differential at constant speed whilst the input motor A1 of the drive line A applies a load torque which varies linearly, as shown in Figure 1B, from a positive maximum value (i.e. the input motor is trying the drive the output shafts of the differential in the same direction as the output motors) to a negative maximum value (i.e. the input motor is trying the drive the output shafts of the differential in the opposite direction to the output motors). The test has a duration of a preset number of shaft rotations (e.g. 540) in order to gather sufficient data.

Referring to Figure 2, an example of the output drive line B or C is shown in more detail. The motor 1 is coupled via a flexible coupling 3 to a flywheel 4. The flexible coupling damps unwanted variations in output torque of the motor. The flywheel is coupled to a safety clutch 8. The clutch has an output shaft coupled to a spindle of a spindle assembly 2 via a spacer 14. One end of the spacer is connected to the output shaft of the clutch and is supported by an intermediate bearing 12. The spindle assembly 2 is coupled to the component under test, in this example an axle containing a differential gear assembly D, via an adapter (not shown). The adapter is connected to the drive line by a connector 10 which is shown as a flange but may have any other suitable form. The components 3 to 10 effectively form a shaft arrangement which connects the motor to the adapter.

In the case of drive line B, the drive line is connected to the axle by an instrumental adapter B6.

The instrumented adapter B6 comprises a torque sensor T an example of which will be described in more detail below.

The output drive line C is identical to the drive line of Figure 2 but it is connected to the axle via an adapter C6 which is a plain, uninstrumented, adapter.

An example of the input drive line A is shown in Figure 3. The drive line A is identical to the drive line of Figure 2 except it is connected to the axle via a plain uninstrumented adapter A6 and the DC torque sensor AT (shown as T in Figure 3) is mounted on the drive line in place of the spacer 14.

The DC torque sensor AT of the input drive line A may be for example an RS 420 sensor available from Datum Electronics, Ryde, Isle of Wight, PO33 2BE, United Kingdom. It comprises a rotor on which are mounted strain gauges and signal processing circuits, a stator and an interface which inductively transfers power from the stator to the rotor for powering the circuits and transfers processed signals from the strain gauges to the stator. The torque transducer AT of the input drive line produces a digital signal. The sampling rate is about for example 1KHz. That relatively low sampling rate limits the drive line rotational speed at which it is possible to gather data samples of the ac torque fluctuations .

An example of the instrumented adapter B6 of the output drive line B is shown in Figure 4. This example is for connecting to a differential gear assembly in the axle D. The adapter is a hollow shaft having a section 40 of reduced outside diameter on which are mounted strain gauges. The section has a protective cover 41. The strain gauges are mounted on the section of reduced outside diameter which is positioned to be as close as possible to the crown wheel of the differential in the axle. Digital signal processing circuits mounted on, or inside, the adapter interface 42 are connected by internal wires to the strain gauges. The adapter interface 42 cooperates with a stator (not shown) to receive power from the stator and to transmit digital signals representing the torque measured by the strain gauges to the stator. The interface is an inductive coupling for at least power transfer. The signals may be transferred inductively or by an RF link. The torque sensor, the signal processor and the interface are available from Datum Electronics, Ryde, Isle of Wight, PO33 2BE, United Kingdom.

As described above , the torque transducer BT is mounted on the adapter B6 so that it is as close as possible to the crown wheel of the differential of the axle under test. The purpose of the torque transducer BT is to detect AC variations in torque originating from the operation of the component under test as close as possible to the source of the variations so as to be substantially uninfluenced by the components of the drive line.

The test apparatus described above with respect to Figures 1 to 4 operates to test axles with a typical maximum Gear Mesh Frequency of 250 Hz. (Gear Mesh

Frequency is discussed in more detail hereinbelow in Annex 1.) The total through put time to test an axle is the sum of the time to load an axle, engage the drive lines with the axle, do the test, disengage and unload. That time is typically 80 seconds. It is desirable to reduce that total through put time.

It is desirable to reduce the total through put time for testing each component.

According to one aspect of the present invention there is provided a drive line for use in an apparatus for testing a component, having meshing gears, of a drive train of a vehicle, the drive line, the drive line having a shaft arrangement for rotating the meshing gears at a predetermined rate and being arranged to have a quiescent zone at a predetermined range of Gear Mesh Frequencies;

the drive line incorporating a torque sensor for sensing AC torque variations due to meshing of the gears,

the torque sensor comprising an array of strain gauges and a signal processor both mounted on a shaft-section of the drive line, the signal processor including AC coupled means for amplifying AC signals output by the array, and a filter arranged to provide a pass band over the said quiescent zone,

wherein the quiescent zone (Z) is in the frequency range;

$$350\text{Hz} < Z \leq 1000\text{Hz} \text{ or more}$$

and means for transmitting the amplified and filtered signals to a stator associated with the shaft-section.

Such a drive line enables a reduction of the total through put time by allowing the drive line to operate faster at a higher Gear Mesh Frequency (GMF) than hitherto achieved.

The drive line and the signal processing of the torque sensor are matched so that torque is sensed at a band of frequencies associated with the higher GMF of interest and the quiescent band of the drive line (at which resonance is minimised). Furthermore processing signals on that shaft improves signal to raise ratio.

In an embodiment the signal processor of the torque sensor comprises an analogue signal processing path comprising the said AC coupled amplifying means, filter and transmitting means.

That allows an analogue representation of the AC torque variation which may be +0.5Nm is represented by a full analogue scale of, for example, 0 to 5V.

In an embodiment the signal processor further comprising a digital signal processing path comprising a DC coupled amplifier for amplifying the output of the array, a digital processor for sampling and digitally processing the samples, output of the DC coupled amplifier, and further transmitting means for transmitting the digitally processed samples to the stator.

That allows for an n-bit representation, where n is 8, 16, 24, 32 or any other suitable number of bits, of both;

i) the average DC torque; and

ii) the AC torque measured in the analogue path

This AC torque can be accurately reversed on the shaft. "On" the shaft also includes doing the processing inside the shaft if it is hollow.

According to another aspect of the present invention, there is provided a drive line for use in an apparatus for testing a component having rotatable parts of a drive train of a vehicle, the drive line comprising;

a shaft arrangement for coupling to the component under test to rotate the said rotatable parts,

a flywheel (4) at one end of the shaft arrangement,

a motor (1) coupled to the flywheel for rotating the flywheel and thus the shaft arrangement, and

a bearing arrangement (2) supporting the other end of the shaft arrangement, wherein a torque sensor (AT', BT) is arranged on the shaft arrangement between the flywheel and the bearing arrangement and arranged to sense AC torque variations due to the operation of the component under test.

Thus, in accordance with another aspect of the invention, the torque sensor is placed not on the adapter but on the drive line between the flywheel and the spindle. In an example the torque sensor is adjacent the spindle being spaced from the adapter by the spindle. The conventional practice and knowledge in the art teaches that the torque sensor should be as close as possible to the component under test: i.e. on the adapter. The variations in torque to be detected derive from for example the manner in which gear teeth in the component mesh, inaccuracies in the form of the teeth, and inaccuracies in the form of the bearings in the component. It would be expected if the torque sensor is positioned as taught by the present invention it would not accurately measure the properties of the component because the spindle which also comprises a shaft which has significant inertia, and bearings supporting the shaft, would introduce errors in the measurements. However tests have shown that the torque sensor of the present invention indeed provides an accurate measure of torque variation resulting from the component. Those tests were carried out using an experimental drive line in accordance with the invention but with an adapter also having a torque sensor. The outputs of the two torque sensors were compared. The torque sensor spaced from the component by the spindle gave similar results to the torque sensor of the adapter. The main difference was that the torque sensor of the adapter gave a signal of greater amplitude than that of the other sensor.

For a better understanding of the present invention, reference will now be made by way of example to the accompanying drawings in which:

Figures 1 to 4 show an example of the prior art as discussed above;

Figure 5 is a simplified schematic plan view of a first example of a test apparatus in accordance with the present invention;

Figure 6A is a simplified schematic plan view of a second example of a test apparatus in accordance with the present invention;

Figure 6B shows a modification of the apparatus of Figure 6A;

Figure 7 is a simplified schematic plan view of a third example of a test apparatus in accordance with the present invention;

Figure 8 is a cross-sectional view of a spindle assembly useful in a drive line of a test apparatus in accordance with the invention;

Figures 9A and B are schematic diagrams of a DC torque transducer useful in the test apparatus of Figures 1, 5, 6B and 7;

Figure 10 is a block diagram of a torque transducer useful in the present invention; and

Figures 11 and 12 are diagrams relating to the operation of the transducer.

Section A - Structures of Test Apparatus.

In this section A, there are described the structures of examples of test apparatus according to embodiments of the invention.

FIRST EXAMPLE, Figure 5.

Referring to Figure 5 the test apparatus comprises an input drive line A identical to the input drive line A described above, an example of which is shown in Figure 3. The apparatus has an output drive line C identical to the output drive line C described above, an example of which is shown in Figure 2. The apparatus also has an output drive line B' in place of the drive line B described above. The drive line B' differs from the drive line B in that the drive line is connected to the component under test by an adapter B6' which is a plain, uninstrumented, adapter and the torque sensor BT is placed in the drive line. For example the drive line B6' may be as shown in Figure 3, with the torque sensor BT placed between the intermediate bearing 12 and the spindle assembly 2. In this example of the invention, the torque sensor BT is designed to detect AC variations in the torque which variations are due to the operation of the component under test substantially uninfluenced by the drive line. The torque sensor BT feeds torque signals to the data acquisition device DA.

The torque sensor may be placed elsewhere in the drive line between the flywheel 4 and the spindle assembly 2. The apparature may also have a complete driveline B' in place of driveline C so that AC torque fluctuations can be measured simultaneously at both outputs of the axle.

A suitable digital torque transducer BT is available from Datum Electronics, Ryde, Isle of Wight, PO33 2BE, United Kingdom. The transducer will be described in more detail hereinbelow.

The first example of the invention has the advantage that only plain adapters are required. Different adapters are required for each different model of component under test and instrumented adapters are expensive compared to plain adapters. However, as discussed above, it is surprising that the AC variations in torque due to the operation of the component under test can be reliably detected by a sensor which is not in the adapter and as close as possible to the gears in the component under test.

SECOND EXAMPLE, Figure 6

Referring to Figure 6, the second example of the invention comprises: an input drive line A' different to the drive line A; an output drive line B identical to drive line B described above (i.e. it does not include a torque sensor) an example of which is shown in Figure 2; and a drive line C identical to drive line C above, an example of which is shown in Figure 2. Drive lines B and C are connected to the axle D by plain uninstrumented adapters. The drive A' has a torque controller A8 as described above. The drive lines B and C have a speed controller B8 as described above.

Drive line A' is also connected to the axle by a plain adapter. The drive line A' differs from the drive line A in that the DC torque sensor T of drive line A is replaced by a torque sensor AT' which senses both DC torque for feeding back to the torque controller A8 but also AC torque variations due to the component under test. The torque sensor AT' feeds its AC torque signals to the data acquisition device DA. The DC torque signals are fed to the controller A8. A suitable torque sensor is available from Datum Electronics and will be described below in the section headed "Torque Sensors".

The second example of the invention has the advantage that only plain adapters are required. Different adapters are required for each different model of component under test and instrumented adapters are expensive compared to plain adapters. However, as discussed above it is surprising that the AC variations in torque due to the operation of the component under test can be reliably detected by a sensor which is not in the adapter and as close as possible to the gears in the component.

The second example also has the advantage that only one torque sensor is needed and that is on the input line.

In a modification of the drive line A', as shown in Figure 6B, instead of one torque sensor which detects both DC and AC torque, separate DC and AC torque sensors AT and AT'' may be provided as shown schematically in Figure 6B. DC torque sensor AT is identical to the sensor of Figure 3. AC torque sensor AT'' may be as described below.

THIRD EXAMPLE, Figure 7.

Referring to Figure 7, the third example of the invention comprises: an input drive line A identical to the drive line A described above , an example of which is shown in Figure 3, and having a DC torque sensor AT; and output drive lines B and C as described above, examples of which are shown in Figure 2. The output drive lines B and C are connected to the axle under test by plain adapters. Drive line A is connected to the axle by an instrumented adapter A6' having a torque sensor AT'. An example of the torque sensor AT' is described in the section "Torque Sensors" below.

The torque sensor AT' of the adapter A6' feeds its signals to the data acquisition device DA.

SPINDLE ASSEMBLY 2, Figure 8.

As discussed above, it would be expected if the torque sensor is positioned between the intermediate bearing 12 and the spindle 2 it would not accurately measure the properties of the component because the spindle which also comprises a shaft which has significant inertia, and bearings supporting the shaft, would introduce errors in the measurements. However, it has been found that the torque sensor so positioned does indeed detect the variations in torque due to the component under test.

Figure 8 is an axial cross sectional view of an example of the spindle assembly 2. The spindle assembly 2 comprises a case 20, through which a steel part shaft 21 passes. The part shaft 21 has a flange 22 at one end for connecting the shaft to the adapter 6. Other means of connecting the part shaft 21 to the adapter 6 may be provided, for example a spline, or a clutch for example a hydraulic clutch. At the other end, the part shaft 21 has a connector 23 for connecting to a part shaft of the torque sensor. The connector 23 may be a spline, keyed shaft, a clutch or any other suitable connector.

The part shaft 21 is supported for rotation in the case 20 by two pairs of angular contact bearings 24. The bearings 24 are spaced apart by a spacer 25 the bearings being maintained in position at one side by the case 20 and at the other by the spacer 25.

The spacer 25 may be of steel and the angular contact bearings may comprise conventional steel races with steel balls. However in an advantageous example, the spacer is of a lighter material e.g. Aluminium or other suitable light material and the balls of the bearings are of ceramic. Using a lighter spacer 25 reduces the inertia of the spindle and using ceramic balls in the bearings reduces torque variations and rotational inertia due to the operation of the spindle assembly. That increases the accuracy of measurement of the torque variations of the component under test by reducing the influence of the spindle on the measurements. Such a spindle assembly may be used in the input drive line and in both the output drive lines of Figures 5 to 7.

Alternatively, such a spindle may be used only in a drive line (A of Figure 7, A' of Figure 6A or B' of Figure 5) which includes an AC torque sensor BT, AT'.

DC Torque Sensor AT

Referring to Figures 9A and B, the DC torque sensor AT is for example mode RS420 from Datum Electronics. It may be used as the DC torque sensor AT of Figures 1A, 5 and 6B. It has a shaft 51 with couplers 50 for coupling the shaft 51 to the intermediate bearing 12 on one side and the spindle 2 on the other. Each coupler 50 may be for example a flange, a spline, or a key, amongst other possibilities. Mounted on the shaft 51 are strain gauges 52 which sense strain of the shaft due in this example to variations in torque applied to the shaft. The strain gauges are connected to rotor electronics which may be mounted on the shaft or, if the shaft is hollow and space allows, in the shaft. The rotor electronics convert the analogue output of the strain gauges to digital and perform other signal processing. The strain gauges and the rotor electronics (where they are not within the shaft) are housed in a rotor 53 mounted on the shaft. The shaft 51 and rotor 53 is surrounded by, and rotate within, a stator 54. The stator and rotor have an interface which inductively transfers power from the stator to the rotor to energise the circuitry on or in the shaft and transfers the signals from the rotor to the stator. Data from the strain gauges is transmitted wirelessly from the rotor to the stator. In one example the wireless link is an inductive link but other wireless links may be used.

The sensor has no bearings, the rotor and shaft being supported within the stator by the intermediate bearing 12 and the spindle 20 in the example of Figure 3.

The data is output from the stator 54 via an electrical connector to the data acquisition device DA.

The RS420 torque transducer produces a measure of static torque. It outputs a digital sample signal with a sampling rate of 1 KHz.

Section B - Reducing Through put Time

The apparatus of section A and of Figures 1 to 4 may comprise drive lines and torque sensors as described in this section which allow a reduction in total through put time.

Drive Lines

The drive line has resonance at one or more rates of rotation. By design of the fly wheel, the stiffness of components of the drive line especially shaft sections, and what are termed 'soft' components, and taking into account the adapters and the component under test, the drive line is designed to resonate at frequencies which do not coincide with the frequencies of the torque variations which the apparatus seeks to measure. Indeed, the drive lines are designed to have quiescent zones at those frequencies.

Torque Sensor AT', AT'', BT, Figure 10

The torque sensor of Figure 10 is arranged on a shaft 100 of the test apparatus as indicated in Figures 1 to 3, 5, 6A, 6B or 7.

The sensor comprises an array 101 arranged on the shaft 100, normally on the outside of the shaft.

The sensor comprises an analogue signal processing path P_A and a digital signal processing path P_D. The components of the paths P_A and P_D may be inside the shaft if it is hollow or on the outside of the shaft.

The analogue path P_A is connected to an FM transmitter having at least an antenna 104 arranged on the outside of the shaft and which communicates with a corresponding receiver 105 of a stator arranged in proximity to the shaft 100. The digital path P_D communicates with a receiver on the stator via an inductive coupling 108.

Power is supplied to the sensor by a power supply 1092 on/in the shaft energised by an AC source 109 coupled to it by an inductive coupling 1091.

Referring to Figure 11, assuming the input drive line A of the test apparatus is applying a constant torque to the code D under test, the AC variation which is to be measured is a relatively small variation on the DC torque. For example the DC torque level may be 400 Nm and the AC variation $\pm$0.5Nm.

The analogue output signal of the array 101 is fed to an AC coupled amplifier 102 in the analogue path P_A. The amplified signal is filtered in a filter 103 which will be described in more detail below, and the filtered signal transmitted by the FM transmitter 104.

The analogue output signal of the array 101 is also fed to a DC coupled amplifier 106 in the digital path P_D. The amplified signal is fed to a processor 107 where it is converted to a digital sampled signal at a suitable sampling rate. The processor 107 also receives the filtered analogue signal from the analogue path and samples and digitises that. The processor 107 interleaves the digital samples of the two signals and feeds the resulting bit stream to the inductive coupling 108.

As described in the section "Drive Lines", a drive line resonates at one or more rates of rotation. The effect of such resonance may be regarded as signal noise. Other sources of signal noise are signal processing noise, and transmission noise associated with the FM transmitter/receiver 104/105 and the inductive coupling 108.

The drive line A, B, C is mechanically designed to be relatively quiescent, (not resonate) with a frequency band comprising the GMF at which torque measurement is to take place.

The filter 103 is designed to provide a pass band PB at the frequency band of interest and to attenuate outside that passband.

The processor 107 in the digital path P_D samples and digitises the signal output by the array 101 of strain gauges. It produces average values of DC torque by for example averaging a predetermined number of samples occurring in a window of samples.

The processor 107 also samples and digitises the filtered analogue signal.

In accordance with embodiments of the invention, the GMF frequency to be measured is a band of frequencies in the range

$300\text{Hz} \leq \text{GMF} \leq 1000\text{Hz}$

which for the example of GMF given in Annex 1 corresponds to an input drive line speed of

$1800 \leq \text{speed} \leq 6000$ rpm

The GMF may be for example 750 Hz corresponding to 4500 rpm.

For example the GMF may be in the range:

$400\text{Hz} \leq \text{GMF} \leq 1000\text{Hz}$; or

$500\text{Hz} \leq \text{GMF} \leq 1000\text{Hz}$; or amongst other examples.

These examples assume that the AC torque variations are measured at constant input torque and a constant speed corresponding to the quiescent band of the drive lines.

The signal processing, including the filtering done by the circuit of Figure 10 on or in the shaft substantially improves signal to noise ratio making it possible to measure the AC torque variation sufficiently accurately. It has been found that, in the absence of such processing on the shaft, it is extremely difficult to measure the AC torque variation. Operating at such higher GMFs with corresponding higher shaft speeds significantly reduces the through put time.

The signal processing described here allows the measurement of AC torque variation at such higher GMFs.

In accordance with another example, it has been proposed to measure torque variation as a drive line accelerates from say 500 rpm to 4500 rpm and decelerates back to 500 rpm whereby the through put time may be further reduced because measurements are made over the acceleration/deceleration times which are not so used when measuring at constant speed. However that requires more sophisticated filtering.

The inductive coupling 108 couples the digital path P_D to a receiver/processor 1081 which may have two outputs. The processor de-interleaves the samples on the bit stream and provide the average DC samples to a DC output for use in DC torque control as provided by sensor AT' in Figure 6A. The digital AC output is provided to the Data Acquisition device in parallel with the analogue output, for recording both digital and analogue AC outputs for the purpose of signal analysis to give a measure of the quality of the axle.

Modifications

The torque sensor AT' of Figure 6A is for example positioned as shown at T in Figure 3, that is between the intermediate beams 12 and the spindle assembly 2. However, it may be placed elsewhere in the drive line between the flywheel 4 and the spindle assembly 2.

The spindle assembly 2 may be replaced by another bearing arrangement which supports the shaft of the drive line in a suitable manner. The bearing arrangement comprises ceramic rolling elements, i.e. balls or rollers, in one example. The bearing arrangement may comprise angular contact bearings.

In the examples of Figures 2 and 3, the components of the drive line are precision engineered to minimise torque variations due to the components of the drive line. Apart from the flywheel which is designed to provide high inertia, the other components are engineered to minimise inertia whilst also minimising resonance.

Components to be tested

Whilst examples of the invention refer to testing axles containing differentials, other components containing gear arrangements could be tested, for example gear boxes, and transfer boxes for four-wheeldrives amongst other examples.

In an example of another aspect of the invention, the torque sensor T which produces both AC and DC signal components representing torque variation is mounted on the adapter 6 as shown in Figure 2. The processor P outputs data representing both DC and AC components of torque variation.

Annex 1

Gear Mesh Frequency

When assessing the NVH quality of a component A is usual to quantify the Gear Mesh Frequency (GMF) rather than the rotational speeds of the input drive line A and output drive lines B and C. GMF is the number of times the teeth of gears of the component under test mesh.

Consider for example a reduction gear ratio of 4:1 in an axle under test. The input drive line rotates at 1500 rpm and the output drive lines rotate at 375 rpm.

If an input gear has 10 teeth, at 1500 rpm the GMF is (1500/60 revolutions per second) x (10 teeth) = 250 Hz.

If the output gear has 40 teeth the GMF for it is (375/60) x 40 = 250 Hz, confirming the teeth of the input gear and the output gear mesh at the same rate.

GMF = (RPM/60) x teeth Hz

RPM = (GMF x 60)/teeth Revolutions per minute.

CLAIMS

1. A drive line for use in an apparatus for testing a component having rotatable parts of a drive train of a vehicle, the drive line comprising;

a shaft arrangement for coupling to the component under test to rotate the said rotatable parts,

a flywheel (4) at one end of the shaft arrangement,

a motor (1) coupled to the flywheel for rotating the flywheel and thus the shaft arrangement, and

a bearing arrangement (2) supporting the other end of the shaft arrangement, wherein

a torque sensor (AT', BT) is arranged on the shaft arrangement between the flywheel and the bearing arrangement and arranged to sense AC torque variations due to the operation of the component under test.

2. A drive line according to claim 1, wherein the torque sensor (AT') is also arranged to sense DC torque applied by the motor to the shaft arrangement, the drive line further comprising means (A8, A9) responsive to the sensed DC torque for controlling the DC torque applied to the shaft by the motor.

3. A drive line according to claim 1, comprising a further torque sensor (AT) arranged on the shaft arrangement to sense DC torque applied by the motor to the shaft arrangement, the drive line further comprising means (A8, A9) responsive to the sensed DC torque for controlling the DC torque applied to the shaft.

4. A drive line according to claim 1, in combination with an adapter connected to said other end of the shaft arrangement, the adapter being a plain, uninstrumented, adapter for connecting the drive line to the component under test.

5. A drive line according to any preceding claim wherein the torque sensor (AT') arranged to sense AC torque variations comprises;

a shaft on which is mounted at least one strain gauge and signal processing means for producing from signals generated by the at least one strain gauge a signal represents AC torque variations.

6. A drive line according to claim 5, wherein the shaft is hollow and the signal processor is on the shaft

7. A drive line according to any preceding claim wherein the motor is coupled to the flywheel via a damper for damping torque variations originating in the motor.

8. A drive line according to any preceding claim wherein the said bearing arrangement comprises ceramic rolling elements.

9. A drive line according to any of claims 1 to 7, where the bearing arrangement is a spindle assembly having a shaft supported by two bearing means spaced apart by a spacer, rotatable with the shaft, the spacer being of a light material.

10. A drive line according to claim 9, where the light material is aluminium.

11. A drive line according to claim 9 or 10, wherein each bearing means comprises ceramic rolling elements.

12. A test apparatus for testing a component under test comprising;

at least one output drive line for rotating a shaft of a component under test;

an input drive line for rotating with and for applying a torque to a second shaft coupled to the first shaft of the component under test;

wherein the input drive line comprises an AC torque sensor arranged to sense AC torque variations due to the component under test.

13. A test apparatus according to claim 12 wherein;

the input drive line is a drive line according to any one of claims 1 to 11, and the output drive line comprises a shaft arrangement for coupling to the component under test to rotate the said rotatable parts,

a flywheel (4) at one end of the shaft,

a motor (1) coupled to the flywheel for rotating the flywheel and turns the shaft arrangement, and

a bearing arrangement (2) supporting the other end of the shaft arrangement.

14. A test apparatus according to claim 13, wherein the output drive line is in combination with an adapter connected to said other end of the shaft arrangement, the adapter being a plain, uninstrumented adapter for connecting the drive line to the component under test.

15. A test apparatus according to claim 13 or 14 wherein the motor of the output drive line is coupled to the flywheel via a damper for damping torque variations originating in the motor.

16. A test apparatus comprising a drive line according to any one of claims 13 to 15 wherein the said bearing arrangement of the output drive line comprises ceramic rolling elements.

17. A test apparatus comprising a drive line according to any of claims 13 to 15, wherein the bearing arrangement of the output drive line is a spindle assembly having a shaft supported by two bearing means spaced apart by a spacer, rotatable with the shaft, the spacer being of a light material.

18. A test apparatus according to claim 17, where the light material is aluminium.

19. A test apparatus according to claim 17 or 18, wherein each bearing means comprises ceramic rolling elements.

20. A test apparatus according to any of claims 12 to 19 wherein the input drive line is arranged to rotate at a greater rate of rotation than the at least one output drive line.

21. A test arrangement according to claim 20 where the input drive line has a shaft arrangement and is arranged to rotate its shaft arrangement at a rate of rotation in the range X to Y revolutions per minute.

22. A test apparatus comprising an output drive line for rotating a first shaft of a component under test, wherein the output drive line comprises an AC torque sensor arranged to sense AC torque variations due to the component under test, and an input drive line for rotating with, and applying torque to, a second shaft coupled to the first shaft of the component under test.

23. A test apparatus according to claim 22 wherein the output drive line is a drive line in accordance with claim 1, or any of claims 4 to 11 when dependent upon claim 1; and

the input drive line comprises a shaft arrangement for coupling to the component under test to rotate the said second shaft of the component under test,

a flywheel (4) at one end of the shaft arrangement,

a motor (1) coupled to the flywheel for rotating the flywheel and thus the shaft arrangement, a bearing arrangement (2) supporting the other end of the shaft arrangement and a DC torque sensor arranged to sense DC torque applied by motor to the shaft arrangement, the drive line further comprising means (A8, A9) responsive to the sensed DC torque for controlling the DC torque applied to the shaft by the motor.

24. A test apparatus comprising at least one output drive line, for rotating a first shaft of a component under test, and an input drive line for rotating with, and applying torque to, a second shaft of the component under test, each drive line being connected by an adapter to the component under test;

wherein the adapter of the at least one output drive line is a plain, uninstrumented, adapter and the adapter of the input drive line is an instrumented adapter comprising an AC torque sensor arranged to sense AC torque variations due to the component under test.

25. Apparatus according to claim 24, wherein the input drive line comprises a shaft arrangement for coupling to the component under test to rotate the said second shaft rotatable parts,

a flywheel (4) at one end of the shaft arrangement,

a motor (1) coupled to the flywheel for rotating the flywheel and thus the shaft arrangement, a bearing arrangement (2) supporting the other end of the shaft arrangement, and a DC torque sensor arranged to sense DC torque applied by motor to the shaft arrangement, the drive line further comprising means (A8, A9) responsive to the sensed DC torque for controlling the DC torque applied to the shaft arrangement.

26. Apparatus according to claim 24 or 25 wherein the output drive line comprises a shaft arrangement for coupling to the component under test to rotate the said first shaft,

a flywheel (4) at one end of the shaft arrangement,

a motor (1) coupled to the flywheel for rotating the flywheel and turns the shaft arrangement, and a bearing arrangement (2) supporting the other end of the shaft arrangement and a DC torque sensor arranged to sense DC torque applied by motor to the shaft arrangement, the drive line further comprising means (A8, A9) responsive to the sensed DC torque for controlling the DC torque applied to the shaft arrangement.

27. Apparatus according to claim 24, 25 or 26 wherein the input drive line is arranged to rotate its shaft arrangement at a greater rate of rotation than the at least one output shaft arrangement.

28. Apparatus according to claim 27 where the input drive line is arranged to rotate its shaft at a rate of rotation in the range 1800 to 6000 revolutions per minute.

29. A method of testing an axle, the axle having an input shaft coupled to at least one output shaft by a differential gear assembly, which acts as a reduction gear between the input shaft and the output shaft, the method comprising driving the, or each, output shaft at a predetermined rotational speed using a, or respective, output drive line(s) have shaft arrangement(s) coupled to the output shaft(s) by adapter(s), and applying a predetermined torque to the input shaft using an input drive line having a shaft arrangement coupled to the input shaft by an adapter.

30. A method according to claim 29, wherein the method comprises

sensing AC variations of torque due to the operation of the axle using an AC torque sensor associated with the shaft arrangement of the input drive line and the adapter coupling it to the output shaft of the axle.

31. A method according to claim 30, wherein the AC torque sensor is on the shaft arrangement of the input drive line.

32. A method according to claim 31, where the AC torque sensor is on the said adapter coupling the input drive line to the axle.

33. A method according to claim 29, 30, 31 or 32, wherein the input shaft of the axle and thus the adapter coupled thereto and the shaft of the arrangement of the drive line rotates at a rate in the range 1800 to 6000 r.p.m.

34. A method according to claim 29, 30, 31, 32 or 33, wherein the method comprises coupling drive lines to the axle by plain, uninstrumented adapters; and

sensing AC variations of torque due to the operation of the axle using an AC torque sensor on the shaft arrangement of one of the drive lines.

35. A method according to claim 34, wherein the AC torque sensor is on the shaft arrangement of the input drive line.

36. A method according to claim 34, wherein the AC torque sensor is on the shaft arrangement of the, or one of the, or all of the, output drive line(s).

37. A method according to any one of claims 29 to 36, wherein the AC torque sensor is an analogue torque sensor.

38. A method according to any one of claims 29 to 37, wherein the said torque sensor senses both AC and DC torque and comprising the step of controlling the torque applied by the input drive line in accordance with a reference value.

39. A drive line for use in an apparatus for testing a component, having meshing gears, of a drive train of a vehicle, the drive line, the drive line having a shaft arrangement for rotating the meshing gears at a predetermined rate and being arranged to have a quiescent zone at a predetermined range of Gear Mesh Frequencies;

the drive line incorporating a torque sensor for sensing AC torque variations due to meshing of the gears,

the torque sensor comprising an array of strain gauges and a signal processor both mounted on a shaft-section of the drive line, the signal processor including AC coupled means for amplifying AC signals output by the array, and a filter arranged to provide a pass hand over the said quiescent zone,

wherein the quiescent zone (Z) is in the frequency range;

$350\text{Hz} < Z \leq 1000\text{Hz}$ or more

and means for transmitting the amplified and filtered signals to a stator associated with the shaft-section.

40. A drive line according to claim 39, wherein

the signal processor of the torque sensor comprises and analogue signal processing path comprising the said AC coupled amplifying means, filter and transmitting means.

41. A drive line according to claim 40, wherein

the signal processor further comprising a digital signal processing path comprising a DC coupled amplifier for amplifying the output of the array, a digital processor for sampling and digitally processing the samples, output of the DC coupled amplifier, and further transmitting means for transmitting the digitally processed samples to the stator.

42. A drive line according to claim 41, wherein the digital signal processor also samples and digitally processes the sampled output of the analogue signal processing path, for transmission by the further transmitting means.

43. A test apparatus comprising a first drive line according to any one of claims 39 to 42, for coupling to a first shaft of a component under test, and a second drive line coupled to a second shaft of the component under test.

44. An invention according to any of the claims 1 to 38, comprising a drive line as set out in any one of claims 39 to 43.

For Innovation

-26-

Application No: GB0517844.7

Claims searched: 39-44

Examiner: Jason Clee

Date of search: 25 May 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	GB 2111355 A (Dolby, R. M.) see page 8 lines 27 to 41 and figure 7

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

B7H; G1J; G1W

Worldwide search of patent documents classified in the following areas of the IPC

G01M

The following online and other databases have been used in the preparation of this search report

Online: The Internet, English language full text databases, WPI & EPODOC

The Patent Office
For Innovation

Application No: GB0517844.7
Claims searched: 24-33, 37 & 38
Examiner: Jason Clee
Date of search: 25 May 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	GB 2391071 A (Visteon Global Tech. Inc.)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

B7H; G1J; G1W

Worldwide search of patent documents classified in the following areas of the IPC

G01M

The following online and other databases have been used in the preparation of this search report

Online: English language full text databases, WPI & EPODOC

The Patent Office
For Innovation

-28-

Application No:	GB0517844.7	**Examiner:**	Jason Clee
Claims searched:	34-38	**Date of search:**	25 May 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	34, 35, 37 & 38	US 2005/081644 A (Juranitch et. al.) especially see figure 5, paragraphs 0067 & 0068 and claims 17-20

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

B7H; G1J; G1W

Worldwide search of patent documents classified in the following areas of the IPC

G01M

The following online and other databases have been used in the preparation of this search report

Online: English language full text databases, WPI & EPODOC