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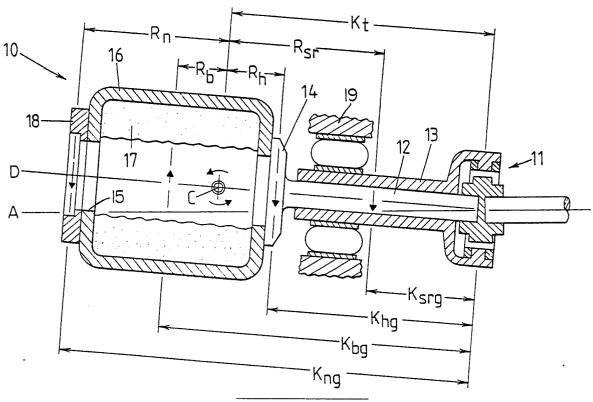
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A centrifuge comprising a bowl 16 supported on a shaft 12, having a gimbal-like mounting 11 and a resilient bearing 19, is provided with a neutralizer ring 18 fixed to the drum 16 around the drum mount 15 such that the neutralizer ring 18 neutralizes the effects of imbalance in a predetermined weight of particulate material 17 and causes the geometric axis and the instantaneous dynamic axis of the rotor system to intersect at said gimbal-like mounting thereby reducing reactive forces exerted on said gimbal-like mounting.



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The present invention relates to centrifuges of the type wherein high speeds are attained through the use of a light-weight composite bowl mounted on a gimbal-mounted shaft.

US-A-4640770 and 4639320 disclose a gimbal-mounted centrifuge to transit the critical speeds of rotation of a centrifuge with little transfer of energy to the gimbal-like structure in which the rotor is mounted, and provide the structure necessary successfully to operate a high speed overhung bowl centrifuge.

In a centrifuge of the type with which the present invention is concerned, the rotating elements are dynamically balanced such that at high speed operation, above the critical speeds, the elements tend to rotate about 15 their geometric longitudinal axis and develop a moment of inertia of WK^2 , where W is the mass (although weight is used in some calculations for simplicity) and K is the radius of gyration of the elements about the axis. When a quantity of centrifuge load material is placed within the centrifuge 20 bowl, the distribution is likely to be unbalanced, thus the unbalanced load causes a radial deviation of the rotating system which causes the system to rotate about a dynamic The radial deviation of the spinning mass results in gyroscopic torque being applied to the system. 25 system is subjected to competing stresses which yield a reactance on the gimbal-like mounting system. reactance or force is excessive, the gimbal-like mounting can soon be destroyed.

The deviation of the dynamic axis of rotation from 30 the geometric axis of the rotating system has long been a concern of centrifuge designers; however, a satisfactory solution which will minimize the effects of an unbalanced condition on a gimballed centrifuge is not previously known.

Numerous patents have issued on dynamic balance 35 systems for centrifugal extractors, such as washing machines and the like, wherein the rotor is mounted in fixed bearings. Some of these such as US-A-2420592 and 3683647 use movable members mounted in association with the bowl which are said automatically to compensate any unbalanced load.

According to the present invention there is provided a centrifuge for extracting fluids from wet particulate material, wherein said centrifuge comprises a rotor system including an overhung composite bowl having a mouth at one 10 end thereof and a base at the other end, a filter media liner proximal the inner surface of the bowl, a plurality of outlet ports through said bowl for the outward discharge of said fluids, a continuous shaft fixed to said base at one end a gimbal-like mounting at a second end of said shaft for 15 driving it in rotation, bearings located intermediate said gimbal-like mounting and said bowl, with said shaft and said bowl being resiliently supported thereon and a neutralizer ring affixed to said bowl about the mouth thereof and being dynamically balanced, with said ring having a weight, 20 W, and a radius of gyration, Kng, about said gimbal-like mounting, such that said neutralizer ring neutralizes the effects of imbalance in a predetermined weight of particulate material and causes the geometric axis and the instantaneous dynamic axis of the rotor system to intersect 25 at said gimbal-like mounting thereby reducing reactive forces exerted on said gimbal-like mounting.

Such a construction enables one to dynamically balance a gimballed centrifuge having a known capacity while the centrifuge is rotating at speeds above the critical or 30 resonant speeds, enabling the centrifuge to be in balance at its drying speeds.

While it is known from US-A-3362198 to use a balancing ring to counter dynamic imbalance in a loaded clothes washer, the rotator is not gimbal mounted and the 35 machine disclosed therein operates under considerably different constraints from the type of centrifuge to which

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the invention is directed. Most notably the balance ring of US-A-3362198 patent is not designed for use with a gimballed system, nor at the speeds at which the centrifuge of the present invention is designed to operate.

Furthermore, from the disclosure, it appears that the balance ring is quite massive relative to the remainder of the system, contrary to the construction possible according to the invention.

The gimballed centrifuge of the invention can have 10 improved longevity and reliability due to the reduced reactive stress placed on the gimbal and it is possible to use a light-weight composite bowl in a high speed centrifuge.

As noted the centrifuge of US-A-4640770 and 4639320

15 utilize a gimbal-like drive connection to power a shaft which turns in a bearing supported on a plurality of bearings of variable resiliency. An overhung bowl is connected to the shaft at a hub such that the shaft and bowl are free to undergo limited radial displacement without

20 inducing severe bending stresses on either the bowl or shaft. As noted however, when an unbalanced load is introduced into the bowl, the combined mass of the bowl and load exert an undesirable centrifugal force which induces a radial diplacement at a velocity sufficient to generate a

25 reactive force on the gimbal of an undesirable magnitude. This is particularly true when the bowl is made of a light-weight composite material.

The construction of the invention utilizes the propensity of the system to induce reactive forces on the 30 gimbal responsive to the unbalanced condition, as if the unbalanced system were a mass W_t located at a radius of gyration K_t relative to the gimbal. For a given rotating system having a known capacity, known operating speed and known masses and location of its components, one can design a neutralizer ring which will minimize the reactive force on the gimbal by causing the geometric axis of the system and

the instantaneous dynamic axis of the system to be aligned at the gimbal. To determine the reactive force on the gimbal without the neutralizer ring, the moment of inertia (WK^2) of each component relative to the gimbal is determined 5 and summed to yield the total $(WK^2)_t$ from which the system radius of gyration K_{+} relative to the gimbal is determined. With a known maximum radial displacement, the gyroscopic effect at the radius of gyration K_{t} can be calculated and the first moment of each component relative to a point at K_{t} 10 can be calculated. The sum of the first moments and the gyro effect are used to determine the resultant force on the gimbal. In the unbalanced condition using a composite bowl, the force on the gimbal at operating speeds will be excessive, leading to failure of the gimbal or the shaft. 15 Therefore the neutralizing ring is located and sized such that the combined torque from the mass and gyro effect of the neutralizer ring about the point $K_{_{\mbox{\scriptsize F}}}$ must be equal and opposite in direction to the torque induced by all the other masses in the system. In determining the torque induced by 20 the other masses, it is apparent that the neutralizer ring must be located outwardly beyond K_{t} . Thus the neutralizer ring must have a diameter acceptable to the size of the bowl, which limits the possible radius of gyration K_{na} of the neutralizer ring relative to the axis. Thus the 25 solution to the problem is the optimization of three variables, the weight of the neutralizer ring $(\mathbf{W}_{\mathbf{n}})$, the radius of gyration of the neutralizer ring relative to the gimbal (K_{nq}) , and the radius of gyration of the neutralizer ring relative to the axis of the system (K_{na}) , and the 30 deployment of the neutralizer ring in accordance therewith.

In order that the invention may more readily be understood, the following description is given, merely by way of example, reference being made to the accompanying drawing, in which the sole Figure is a vertical sectional schematic view of one embodiment of centrifuge according to the invention.

Referring to the Figure, a rotor system 10 of a centrifuge such as described in US-A-4640770 which is incorporated herein by reference, is shown schematically with much of the support structure eliminated for clarity.

5 The rotor system 10 has a geometric or rest axis indicated at A about which it should rotate if perfectly balanced. Input power for rotation is provided via gimbal-like connection 11. A drive shaft 12 rotates in a bearing sleeve 13 which is supported on a suspension bearing 19 of variable 10 resiliency as described in US-A-4640770. A hub 14 affixed to the shaft 12 supports an overhung bowl 16, made of a light-weight composite material, the bowl having a mouth 15 at the end remote from hub 14.

The rotor system 10 is depicted as having undergone 15 a deflection at an exaggerated angle such that the instantaneous dynamic axis is indicated at D. It is to be understood that the Figure is an instananeous representation of the rotor system 10 which in reality would describe an orbit about the geometric axis A. It is also to be 20 understood that the rotor system 10 can be modeled by a set of masses and appropriate radii of gyration. Consequently, the shaft 12 may be considered to have a mass $M_{_{\rm S}}$, a radius of gyration about the gimbal denoted by K_{srg} and a radius of gyration about the geometric axis A, K sa; the hub has a mass 25 M_{h} , and radius of gyration of K_{hg} and K_{ha} ; the bowl and load have a combined mass M_b , radius of gyration K_{bq} and K_{ba} ; the bearing has a mass M_{r} and a radius of gyration K_{rg} about the gimbal. To avoid confusion, the radii of gyration relative to the geometric axis are not designated in the Figure; 30 however it is to be understood that they are physical dimensions which can readily be determined from the geometry of the centrifuge.

While the present invention may be used with any centrifuge having an overhung bowl and gimbal-mounted rotor 35 system, it is particularly useful with a light-weight, high strength composite bowl which has a mass less than the mass

for the hub.

of particulate 17 centrifuged therein. For purposes of illustration, such a system is described and referred to throughout the remainder of the specification.

In the following exemplary system, the weight of the components rather than the mass will be used in description and formula, for the sake of simplifying the discussion. The particulate 17 and bowl have a combined weight of 499 kg, the hub 14 has a weight of 129.36 kg, the shaft 12 has a weight of 72.48 kg, and the weight of the bearing 13 is 10 108.72 kg. The product of the weight of each component and the square of the radius of gyration about the axis, WK², is derived from the physical geometry of each component resulting in the following values:

	Component	w^2 m^2 re axis
15	Bowl and Load	81.13
	Hub	7.25
	Shaft and Bearing	0.147

Also known are: the RPM of the system N - 2400, the maximum radial displacement at the geometric centre of the bowl 20 R = 0.00127 m, and the radius of gyration for each component about the gimbal connection 11, which are $K_{\rm srg}$ = 0.437 m for the shaft 12 and bearing 13 combination, $K_{\rm bg}$ = 1.478 m for the bowl 16 and particulate 17 combination and $K_{\rm hg}$ = 0.866 m

With these values known, the total WK² of the system with respect to the gimbal can be determined by summing the WK² of the components as shown in Table 1.

	<u>Table l</u>		
Component	Weight (Kg)	Radius of	wk ²
		Gyration	
	•	in metres	
Bowl & Particulate	499	1.478 m	1090.06 kg m^2
Hub	129.36	0.866 m	97.01 kg m^2
Shaft & Bearing	181.21	0.437 m	34.61 kg m^2
	809.57		1221.68 kg m^2

From the above totals, the radius of gyration 10 of the system relative to the gimbal, $K_{\mbox{\scriptsize t}}$, may be calculated by

$$K_{t} = \left(\frac{WK^{2}}{W}\right)^{1/2} = \left(\frac{1221.68}{809.57}\right)^{1/2} = 1.243$$

15 This radius of gyration K_t is taken to be the point in the system at or about which all of the reactive forces act including the gyroscopic force P induced by the deflection of the unbalanced load.

Thus, the sum of the first moments of the components about a point C located at K_{t} and the gyroscopic effect must be determined to determine the force acting on the gimbal due to the unbalanced condition. These first moments are taken about point C at K_{t} such that clockwise moments are considered positive and counter clockwise negative.

To determine the first moment of each component, determine the radial throw at its radius of gyration relative to the gimbal using the proportion.

$$R_t = 0.00127 \times \frac{Kg}{R}$$

where $K_{\overline{g}}$ is the radius of gyration of the included component 30 relative to the gimbal and R is the distance from the gimbal

to the geometric centre of the bowl, 1.44 m.

The number of gravities for each item is calculated from the relation $a.R_tN^2$ where a is a constant. Thus the force exerted by each item is the product of the components weight and the specific gravities.

The moment arm for each component is determined by the relation $R_g = K_g - K_t$, where R_g is the moment arm of each component. At speeds above the natural frequency, each balanced component exerts its force toward the axis of rotation whereas the unbalanced load exerts a force away from the axis consequently.

Table 2 shows the summation of the moments about K_t .

Table 2

Component	Radial Throw	g's	Weight kg	Force kg m	Mom. Arm	Moment kg m
Bowl &						
Load	0.00127	8.35	499	4166.65	0.235	979.16
Hub	0.00076	4.91	129.36	635.16	0.377	239.46
Shaft &						
Bearing	0.00058	2.46	181.21	445.78	0.806	459.5
						1578.12

Additionally, the gyro precessional torque P_{kt} of the rotating components is determined and summed with the first moments using the expression

15
$$P_{kt} = \left(\frac{W}{g}\right) \left(K_r^2\right) \left(\frac{N}{30}\right) \left(\frac{V}{K_t}\right)$$

where V is the linear velocity of a point on the axis at ${\rm K}_{\rm t}$ from the gimbal and W is the weight of the rotating parts and ${\rm K}_{\rm r}$ is the radius of gyration of the rotor system

relative to the axis thereof.

Since the instantaneous linear velocity of the point is tangent to the orbit of the dynamic axis, the resultant gyroscopic precessional torque is directed toward the geometric axis at K_t and has a magnitude of -539 kg.m, thus the sum of the first moments and precessional torque at K_t is 1039.12 kg.m and the force on the gimbal as a result is

$$F = \frac{1039.12 \text{ kg.m}}{1.243} = 835.98 \text{ kg}$$

which is sufficient to damage the centrifuge.

From the analysis of the moments of force about K_{+} , it can be seen that a counter-balancing moment of force is 15 required to neutralize the effect of the unbalanced load and that the mass needed must be located at a distance greater than K_{t} from the gimbal. To minimize the required mass, a neutralizer ring 18 is mounted about the mouth 15 of the bowl 16 and is affixed thereto, for example by means of nuts 20 and bolts, so that it does not move relative to the bowl. In the described example, this will locate the ring at a radius of gyration K_{nq} about the gimbal of 1.99 m. Of course, the addition of the neutralizer ring 18 changes the WK^2 of the entire system, so each of the preceding 25 calculations must be performed to optimize the mass. radius of gyration of the neutralizer ring 18 about the gimbal is constrained by the displacement of the bowl mouth 15 from the gimbal and the radius of gyration of the neutralizer ring 18 about the axis is constrained by the 30 size of the bowl mouth.

The diameter of the ring 18 thus has a lower limit defined by the size of the bowl mouth. The thickness and outer diameter of the ring 18 are dimensions which can be

varied to locate the centre of mass at the desired K_{na} and K_{ng}. Therefore the most easily changed variable is the mass of the ring, although both K_{na} and K_{ng} can be varied by varying the geometry of the bowl. The mass of the ring 18 is varied by the selection of the ring material, which may be any material which can be formed into a solid ring and which will withstand the forces generated by the centrifuge, and by the physical dimensions selected for the ring.

Table 3 provides the relationship between the mass 10 of the neutralizer ring 18 and the force exerted on the gimbal when $\rm K_{ng}$ is taken to be 1.99 m.

	5	Table 3	
Weight of	\mathtt{WK}^2 of	First	Gimbal
Neutralizer	Ring m ²	$\underline{\texttt{Moment}\ \mathtt{m}}$	Reaction
Ring			
Zero	Zero	1032.5	830.54
90.72	10.66	78.13	58.97
98.88	11.61	-5.98	-4.54
99.72	11.71	-14.70	-10.89
102.06	11.98	-36.36	-27.22
104.33	12.75	-60.33	-44.91
136.08	15.97	-469.32	-323.41

From Table 3, it should be apparent that it is insufficient to simply place a balanced ring outwardly of the mouth of the bowl 10. Rather the ring must be of a 25 particular mass according to the weight of the system which it must neutralize and it must be located appropriately. For example, if the mass were held constant at 98.88 kg and the radius of gyration K_{ng} were extended or shortened by 5.08 cm, the force on the gimbal would increase to in excess 30 of 52.16 kg which would severely stress the gimbal.

It may thus be seen that the neutralizer ring may be

constructed which will effectively minimize the reactive force on the gimbal of the system and thus greatly enhance the useful life of the gimbal mounted centrifuge.

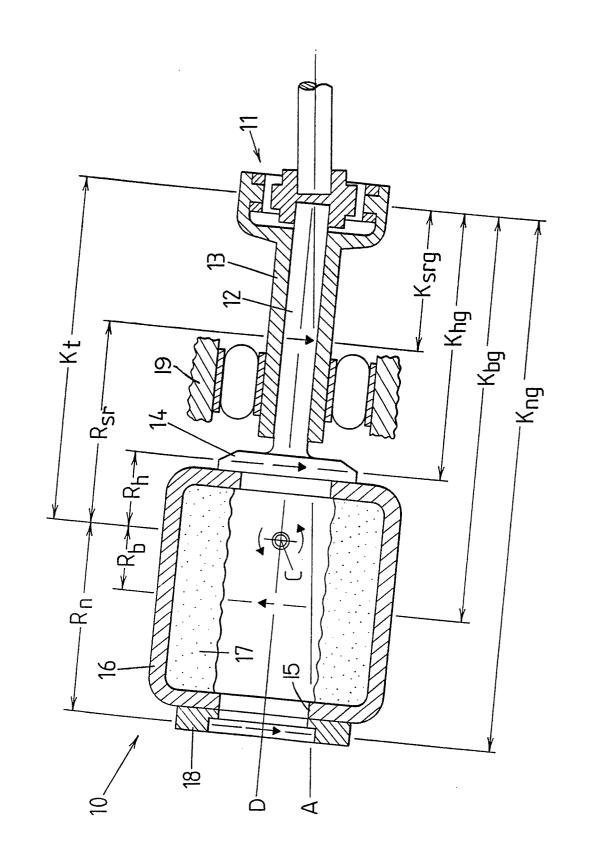
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CLAIMS

- 1. A centrifuge for extracting fluids from wet particulate material, wherein said centrifuge (10) comprises a rotor system (11-16) including an overhung composite bowl (16) having a mouth (15) at one end thereof and a base (14) at the other end, a filter media liner proximal the inner surface of the bowl, a plurality of outlet ports through said bowl for the outward discharge of said fluids, a continuous shaft (13) fixed to said base (14) at one end a gimbal-like mounting (11) at a second end of said shaft for 10 driving it in rotation and bearings (19) located intermediate said gimbal-like mounting (11) and said bowl (16), with said shaft and said bowl being resiliently supported thereon characterised in that a neutralizer ring (18) is affixed to said bowl about the mouth thereof and 15 in that said ring is dynamically balanced, with said ring having a weight, W, and a radius of gyration, Kng, about said gimbal-like mounting (11), such that said neutralizer ring (18) neutralizes the effects of imbalance in a predetermined weight of particulate material (17) and causes 20 the geometric axis and the instantaneous dynamic axis of the rotor system to intersect at said gimbal-like mounting thereby reducing reactive forces exerted on said gimbal-like mounting.
- 2. A centrifuge according to claim 1, characterised
 25 in that the neutralizing ring (18) has an effective
 diameter, mass, and moment of inertia thereof, WK², such
 that when said rotor system is operating above the natural
 frequency of vibration thereof the annular mass of said ring
 negates minor imbalance in said particulate material in said
 30 centrifuge and causes the geometric axis (A) and the
 instantaneous dynamic axis (D) of said rotor system to
 intersect at said gimbal-like mounting (11), where W is the

weight of the ring and K is the radius of gyration of the ring relative to the geometric axis of the system.

3. A centrifuge according to claim 1 or 2, characterised in that said neutralizer ring (18) is located a distance, d, from the radius of gyration, K_t, of said rotor system about said gimbal-like mounting such that the first moment of force due to the neutralizer ring about a point on the axis of the rotor system at said radius of gyration, K_t, acts in opposition to the first moment of force due to said particulate material (17) about said point, such that the sum of the gyroscopic precessional torque and the first moments of force about said point due to said rotor system, neutralizer ring and particulate material is minimized.



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