ROTOR BALANCER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a method and apparatus for dynamically balancing rotary bodies or rotors such as gyroscopes. More particularly, this invention relates to a method and apparatus useful for balancing rotors while they are being rotated at their normal, often high, operating speeds.

2. Description of the Prior Art

The purpose of any dynamic balancing method or apparatus for rotating of bodies is to achieve coincidence between the bearing axis and inertial axis of rotation of the rotary body to prevent the generation of unbalanced rotational forces when the element is run at normal operating speeds. Such unbalanced forces generated by a rotor can cause severe stresses on the bearing assemblies. In cases where electrical or inertial sensors are associated with the operation of the rotating body, the presence of such unbalanced forces can cause distortions of such magnitude as to materially limit the performance of devices incorporating the rotary element, and even can totally impair the operation of the devices by causing the ultimate destruction of the rotating component due to structural failure.

The dynamic balancing of rotary bodies, such as gyroscope rotors, is presently accomplished in a series of repetitive steps wherein the rotor being balanced is rotated at its normal operating speed; while in rotation the point of imbalance is sensed and indexed on the rotor; the rotor is then brought to rest; and a small portion of the material forming the rotor at the indexed imbalance point is removed. In order to obtain the desired degree of balance it is normally required that the above steps be repeated about 4 or 5 times. This repetitious procedure of bringing the rotor up to speed or "revving up" the rotor, sensing and indexing the points of imbalance, bringing the rotor to rest, and removing material from the rotor is tedious, time consuming, and materially limits the productivity of conventional balancing machines and the production of precision rotary elements.

Another method that has been utilized is the placement of small lead shot or pellets in a compartment of the rotor and obtaining adjustment by adding or removing quantities of pellets as determined by the above-described presently employed process.

Another known means of dynamic balancing is that of U.S. Pat. No. 2,346,975 wherein an arcing electrode in response to a piezoelectric crystal indication of imbalance removes mass. However, such an arc is of long duration and will smear out a considerable portion of the periphery of the device to be balanced.

In another means, that of U.S. Pat. No. 2,449,563, duration of balancing forces and balance couples are considered in response to variation of the shape, size and orientation of a luminous curve which exhibits prevailing imbalance conditions on a cathode ray oscilloscope. The means of this patent is not suitable since it does not provide the advantages afforded by the invention of synchronization of revolving of the removing tool with the work to enable precision, ease, speed and control of operation.

With the advent of smaller, rugged gyroscopes, which are critically required in manufacture such as of stable platforms and other navigational aids, the disadvantages of presently available balancing processes have become a serious production bottleneck.

In an effort to speed up the balancing process, attempts have been made to utilize a stationary electrical discharge or pulsed laser beam to boil material from the spinning rotor of such gyros. However, due to the very high rate of rotation of the rotor the required pulse duration is extremely short, and in the order of a microsecond. Such short pulses are unable to deliver sufficient energy to obtain the necessary boil-off. When longer pulses were used in the prior art the energy applied was not sufficiently localized and resulted in a smearing

out of the beam energy over part of the circumference of the rotors, sometimes to such an extent that there was insufficient concentration of energy to effect boil-off and/or balancing. When "Q" spoiled lasers are used the problem of excessive pulse duration is solved at the expense of great apparatus complexity and the fact that the total energy content of a "Q" spoiled laser pulse is insufficient to remove the quantities of material necessary to obtain balance.

SUMMARY OF THE INVENTION

The present invention is directed to a method and apparatus for dynamic balancing of an unbalanced rotating body while rotating at normal operating speed by utilizing a continuous or intermittent laser beam. The beam is reflected into a rotating circular path by a rotating optical means such as a mirror (or refracted by a rotating lens) to impinge upon surface projection of heavy points which cause rotor imbalance until the imbalances are removed by material being melted and boiled-off from the surface of the rotor. The imbalance is first sensed and the rotor oriented to have a surface of the rotor heavier half facing the mirror or lens and the projection of the heavier portion upon the rotor surface may be marked or otherwise indicated. The rotor and reflecting mirror or deflecting lens are brought into in phase relationship and are synchronously rotated so that the point where the beam impinges on the rotor remains in an approximately fixed relationship during rotation of the rotor. In the described embodiments a phase shifting control may be provided in the rotor and beam deflector (mirror or lens) drive system to enable an operator to adjust the relative rotational phase of the rotor and beam deflector and thereby adjust the point of impingement of the beam on the rotor to coincide with points of rotor imbalance. The points of imbalance are sensed at a particular angular position in the rotation of the rotor. Sensing may be effected, for example, by a standard acceleration sensitive transducer. The transducer responsively actuates a stroboscopic light to illuminate an indicating disc associated with the revolving mirror or lens to determine and provide the degree of phase shift required to obtain coincidence between the point of impingement of the reflected laser beam and the angular location of rotor imbalance being sensed. Circuit means which may be actuated by the output of the transducers may be provided to cut off the laser beam when sufficient material has been boiled-off from the rotor to remove the imbalance.

The previously enumerated disadvantages and limitations encountered in attempts in the art to utilize a stationary laser beam to dynamically balance a rotor while spinning at a high rate of speed have been overcome in the present invention by rotationally deflecting the laser beam in a circular path synchronously with the rotating rotor. This arrangement permits the beam to continuously play on the imbalance point until sufficient energy has been delivered to effect melting and boil-off of the imbalance.

Accordingly, it is an object of the present invention to provide a new and improved method and apparatus for dynamically balancing a rotating body while in rotation at operational speeds.

It is another object of the present invention to provide means whereby a laser beam will impinge upon a point of imbalance of a body in rotation to remove material until dynamic balance of the body is effected.

Still a further object of the present invention is the provision of means whereby portions of a rotating body can be melted and boiled away from the body while it is in continuous rotation to obtain a dynamic balance of the body.

Still another object of the invention is the provision of means whereby a laser beam is deflected in a synchronously rotating path with, while either intermittently or continuously operating and is substantially continuously disposed to focus on, a fixed surface point of the body, for example the surface area projection of an internal imbalance portion, while the body is in a path of rotation, to boil-off imbalancing portions of the body until the body has been dynamically balanced.