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DVL ANGULAR VELOCITY RECORDER

By Wolfgang Liebe

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INTRODUCTION

In many studies, especially of nonstationary flight motion, it is necessary to determine the angular velocities at which the airplane rotates about its various axes. The three-component recorder is designed to serve this purpose.

If the angular velocity for one flight attitude is known, other important quantities can be derived from its time rate of change, such as the angular acceleration by differentiations, or - by integration - the angles of position of the airplane - that is, the angles formed by the airplane axes with the axis direction presented at the instant of the beginning of the motion that is to be investigated.

MODE OF OPERATION

A revolving gyroscope rotated at angular velocity  $\omega$  about an axis perpendicular to the axis of revolution produces a moment in the plane formed by these two axes. At constant speed of revolution  $\omega_k$  this moment is a measure for the angular velocity  $\omega$  at which the gyroscope is moved. If the gyroscope is secured by a spring in the plane in which the moment acts, the deflection of the spring is proportional to the torque - that is, proportional to the angular velocity. The three axes of the gyroscope are designated as follows:

1. The axis of revolution

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\*"Dreiachsen-Winkelgeschwindigkeitsschreiber der DVL." Luftwissen, vol. 5, no. 8, Aug. 1938, pp. 297-298.

2. The axis of sensitivity (or measuring axis) perpendicular to the axis of revolution
3. The mooring axis, perpendicular to the plane formed by the axis of revolution and the axis of sensitivity

This system of axes is linked to the gyroscope axes. For recording, the instrument is oriented in the airplane along the body measuring axes. At a deflection of the mooring spring the gyroscope axes twist to the amount of the deflection angle  $\Theta$  with respect to the body axes. Since the components of the angular velocity in the body axis system are to be measured, and the sensitivity axis is deflected by the angle  $\Theta$  with respect to the body axis, a measuring error is introduced, because the gyroscope becomes more susceptible to rotations about an axis other than the selected body-fixed measuring axis. For example, if the rolling velocity  $\omega_x$  is to be measured, and the measuring gyroscope is oriented so that its axis of revolution is parallel with the transverse axis of the airplane (y axis) the equation for the spring deflection  $\Theta_x$  reads:

$$\Theta_x = B/c \cos \Theta_x \omega_x + B/c \sin \Theta_x \omega_y$$

where

$\Theta_x$  spring deflection about the mooring axis

B gyroscope impulse,  $B = J_p \omega_k$

$J_p$  polar moment of inertia of gyroscope

c spring constant of mooring spring

From the equation it is apparent that  $\Theta_x$ , with such a one-gyroscope arrangement, is dependent, aside from  $\omega_x$ , on another component of the angular velocity, in the illustrative case chosen here, upon  $\omega_y$ . (This instrumental error occurs also on the English RAF recorder, which has a somewhat similar outward appearance). This error of the simple turn indicator is avoided with a two-gyroscope arrangement in the so-called inertia frame (Patent according to Boykow), as used in the DVL instrument-for-measuring element. If two gyroscopes with

opposite direction of revolution are linked so as to permit only opposite rotation about their mooring axis, two moments are active:

$$M_1 = c_1 \Theta_1 = B_1 \omega_x \cos \Theta_1 + B_1 \omega_y \sin \Theta_1$$

on gyroscope 1, and

$$M_2 = c_2 \Theta_2 = B_2 \omega_x \cos \Theta_2 + B_2 \omega_y \sin \Theta_2$$

on gyroscope 2. The gyroscopes are oppositely rotating; hence

$$B_1 = -B_2 = B$$

and consequently

$$\Theta_1 = -\Theta_2 = \Theta_x$$

when

$$c_1 = c_2 = c$$

Then the moment applied at gyroscope 1 is

$$c \Theta_x = B \omega_x \cos \Theta_x + B \omega_y \sin \Theta_x$$

and at gyroscope 2

$$-c \Theta_x = -B \omega_x \cos \Theta_x + B \omega_y \sin \Theta_x$$

Since the gyroscopes are connected so that opposite moments are additive, parallel moments cancel; the term with  $\omega_y$  disappears. The relation for the double gyroscope in the inertia frame reads:

$$\Theta_x = B/c \cos \Theta_x \omega_x$$

If  $B$  and  $c$  are constants, the spring deflection  $\Theta_x$  is only dependent on  $\omega_x$ . A rotation about any axis other than the actual measuring axis has therefore no effect on the indication of the measuring element.

## DESCRIPTION OF INSTRUMENT

Each angular velocity component has a pair of gyroscopes as a measuring element. All axes are supported in ball bearings to keep the sliding friction at a minimum. Relative to the friction moment the gyroscope rotation is chosen so great that the instrument responds at angular velocities of  $\omega = 0.005 \text{ (s}^{-1}\text{)}$ .

The gyroscopes operate asynchronous motors at 20,000 rpm. A centrifugal force regulator at the three-phase current generator regulates the speed at  $\pm 10$  percent voltage fluctuation to within  $\pm 0.5$  percent. The transformer (fig. 1) fed from a 24- or 12-volt accumulator supplies the three-phase current for driving the gyroscopes.

The gyroscopes are secured by flat springs stressed in torsion. The instrument is fully utilized only when the test range is adapted to momentarily occurring maximum test values. For this reason the springs are interchangeable and in addition, a special device permits the free length of the torsion springs to be varied. In this manner the test range can be doubled separately for each component by a simple handle.

The following test ranges are provided:

$$\begin{aligned}\omega &= \pm 0.005 \text{ to } \pm 0.6 \text{ s}^{-1} \\ &\pm 0.005 \text{ to } \pm 1.2 \\ &\pm 0.005 \text{ to } \pm 2.5 \\ &\pm 0.005 \text{ to } \pm 5.0\end{aligned}$$

The spring deflection is optically recorded. The mooring axis of one of the two gyroscopes of an inertia frame carries a mirror which deflects a light ray corresponding to the spring deflection  $\Theta$ . The deflection is plotted on sensitized paper.

Aside from the three light spots indicating the gyroscope deflection, the recording paper shows time markings at stated intervals controlled by a clock which at the same time produce accurate reference lines for the interpretation.

The sensitized paper is housed in a separate case (fig. 2) easily fitted on the instrument. The paper feed controlled by a counting mechanism is accomplished by electric motor and claw coupling. The paper is 136 millimeters in width. For each velocity component  $\pm 26$  millimeters recording height is available. The case holds approximately 30 meters of paper, which, at a 25 millimeters-per-second feed (adjustable from 10 to 40 mm/s), is equivalent to a test period of 20 minutes.

For the optical recording of special time intervals, such as the start of a control deflection, for instance, a spark gap is provided, the spark appearing on the record as a light dash. This spark gap, coupled across a tachometer with the crankshaft, can also be used in simple manner as revolutions per minute recorder. This way the three components of the angular velocity of the airplane  $\omega_x$ ,  $\omega_y$ , and  $\omega_z$  and of the propeller  $\omega_p$  (fig. 3) are obtained in one record.

#### MEASURING ACCURACY

The accuracy of the  $\Theta$  indication is impaired by bearing friction and bearing play. Both effects together cause a maximum error of around  $\pm 0.01(s^{-1})$  - that is, about  $\pm 1$  percent of the greatest value in the test range of 0 to  $1.2(s^{-1})$ . The record interpretation is exact up to  $\pm 0.25$  millimeter - that is to say, within about 1 percent for 26 millimeters total record height. An instrumental accuracy of  $\pm 2$  percent of the maximum test value is thus obtainable.

Requisite for this accuracy of interpretation is the absence of great oscillations. The gyroscopes are provided with a simple damping device insuring interpretable records even on approaching resonance between propeller rpm and natural frequency of the measuring element. The natural frequency of the gyroscope oscillating in the mooring springs depends upon the spring stiffness, hence varies for different test ranges. It lies at 10 Hertz for the  $\omega$  range 0 to  $1.2 s^{-1}$ . Motion processes up to a frequency of about 2 Hertz are thus reproduced without distortion.

Translation by J. Vanier,  
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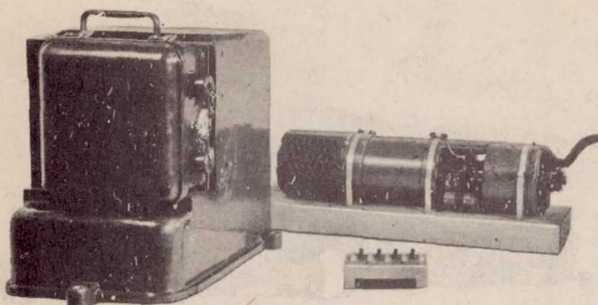


Figure 1.- DVL-angular velocity recorder with 24 volt transformer.

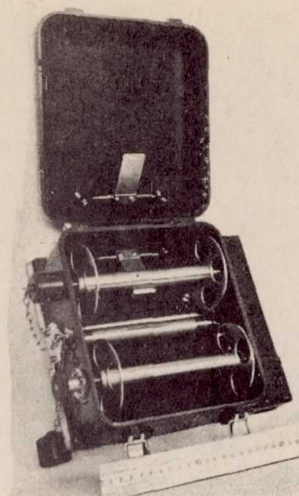


Figure 2.- Paper holder- the feed change is varied by changing the the cog wheels.

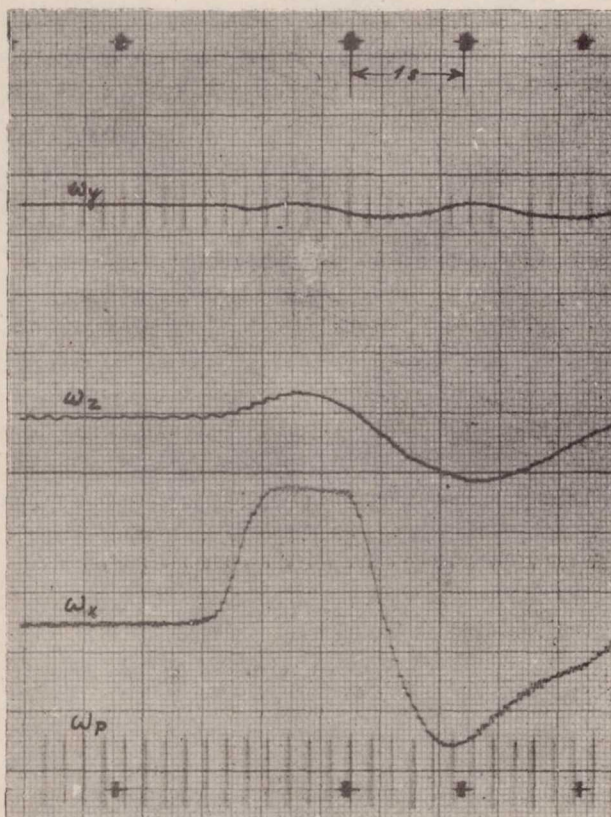


Figure 3.- Section of a test record-a 1 cm deflection defines an angular velocity of  $\omega = 0.46 \text{ s}^{-1}$ . The light spots at the lower border indicate the number of crankshaft rotations and hence the angular velocity  $\omega_p$  of the propeller.