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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM 25

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By

E. Everling.

Translated from
"Zeitschrift für Flugtechnik und Motorluftschiffahrt,"
Vol. X, Nos.17/18.

June, 1921.

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(Communicated by the German Aeronautical Laboratory)**

At the Aero-Technical Conference of the "Wissenschaftliche Gesellschaft für Luftfahrt," held on April 23, 1919, one of the most important of the objections brought forward by Herr SEPPELER***with regard to the dynamometer hub****was that "the engine must continue to retain its flywheel."

As this opinion delayed the development of the dynamometer hub at that time, and it might even now give rise to erroneous views concerning its merit, we shall make a brief investigation of the extent to which the dynamometer affects the well-known flywheel action of the propeller. This point will be discussed later on, and will be applied to coupling, toothed gear, etc.

W. HOFF*****has proved that the want of symmetry of a 4-cylinder 100 HP engine is reduced from 0.517 to 1/180 kg. m/sec.^{2} of the inertia moment through the weight of the propeller. The

* From "Zeitschrift für Flugtechnik und Motorluftschiffahrt," Vol. X, Nos.17/18.

** Obtained by the courtesy of Prof. K. KUTZBACH.

*** See "Zeitschrift für Flugtechnik und Motorluftschiffahrt," Nos. 9/10, p.112.

**** The DYNAMOMETER of the D.V.L. is written by W. STIEBER, in "Technische Berichte," Vol. III, p.221. Compare measurements of same in "T.B." Vol. I, p.54, by E. EVERLING.

*****Compare W. HOFF, "Jahrbuch der Deutschen Versuchsanstalt für Luftfahrt," Vol. I, 1912-13, p.224.

unequalized damping effect of the power obtained enters into the calculation as in the case of every power machine - in this case it is the resistance of the air, which increases with the square of the number of revolutions and brakes the acceleration of the screw, but which augments the diminution of velocity.

This RESISTANCE OF THE AIR, which is not generally taken into account, is yet of actual importance when a movable organ, such as the dynamometer, is inserted between the engine and the propeller, as the propeller then oscillates freely between a capsule tappet-rod and a collar, with a clearance of about 5°. In place of the usual rigid joint between the engine and the propeller, the CLOSED CIRCUIT is here brought about by the resistance of the air. The following article will show that THIS COUPLING SUFFICES TO ENSURE THE FLYWHEEL ACTION OF THE ENGINE. We must then find out to what extent the engine may be retarded until the propeller is lifted in consequence of its inertia to the resistance of the hammer of the rotary moment capsule, so that it oscillates freely or strikes against the stop. The retarding rotary moment must then be at least equivalent to the rotary moment absorbed by the propeller:

$$\theta \cdot \frac{d^2 \varphi}{d t^2} = \theta \cdot \frac{d \omega}{dt} = - M = - M_o \cdot \frac{\omega^2}{\omega_o^2} \quad . \; . \; . \; . \; . \; . \; . \; (1)$$

in which

θ = the moment of inertia (in kg. m/sec.²)

φ is the angle of rotation, $\omega = \frac{d\varphi}{dt}$ the angular velocity (s^{-1}), M the rotary moment (kgm) absorbed by the propeller, M_o the value of which for $\omega = \omega_o$.

By integrating (1), we get the following equation for the decrease of the angular velocity of the freely running propeller (initial velocity ω_o)

$$\omega = \frac{\omega_o}{1 + \frac{M_o}{\theta \omega_o} \cdot t} \quad \ldots\ldots\ldots\ldots \quad (2)$$

That is, for the proportional decrease of angular velocity due to the braking action:

$$1 - \frac{\omega}{\omega_o} = \frac{1}{\frac{\theta\ \omega_o}{M_o\ .\ t} + 1} \quad \ldots\ldots \quad (3)$$

If we replace the angular velocity by the ordinary number of rotations per minute n or n_o and insert HOFF'S numerical value, the result is as follows:

$$1 - \frac{n}{n_o} = \frac{1}{\frac{\pi}{30} \cdot \frac{\theta\ n_o}{M_o\ t} + 1} =$$

$$= \frac{1}{\frac{\pi}{30} \cdot \frac{0.517\ n_o}{45.6\ t} + 1} = \frac{1}{\frac{n_o}{840\ t} + 1} \quad \ldots (4)$$

especially when the normal number of revolutions n_o = 1200 r.p.m.

$$1 - \frac{n}{1200} = \frac{1}{\frac{10}{7\,t} + 1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (5)$$

This value therefore represents the highest possible variation in the number of revolutions during the time t, above which the propeller becomes free; that is, the flywheel effect ceases. The time between the sparking of two cylinders may therefore be:

$$t = \frac{60}{1200 \cdot 2} = \frac{1}{40} \text{ s.}$$

The variations in the number of rotations amount to a maximum of 21 r.p.m. in an entire second, and to a maximum of 500 r.p.m. in throttling down.

On the other hand, the minimum time that must be taken for a determined reduction of the number of revolutions is as follows:

$$t = \frac{\theta \omega_o}{M_o} \left(\frac{\omega_o}{\omega} - 1 \right) = \frac{\pi}{30} \cdot \frac{\theta\, n_o}{M_o} \left(\frac{n_o}{n} - 1 \right) =$$

$$= \frac{n_o}{840} \left(\frac{n_o}{n} - 1 \right) = \frac{10}{7} \left(\frac{1200}{n} - 1 \right) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (6)$$

The results are shown in the following table:

For the reduction of the number of revolutions to

n = 1100 1000 900 800 700 600 500 400 300 200 100 r.p.m.

the minimum requisite

t = 0.13 0.29 0.48 0.71 1.02 1.43 2.00 2.86 4.29 7.15 15.7s.

It is IMPORTANT to know if such duration of time will be maintained in ordinary working when one of the cylinders does not work and when the engine is throttled down; in other words, if the retardation of the rotary parts of the engine and of the dynamometer is higher than as above calculated. If equation (1) be also applied to this crankshaft system with the smallest inertia moment , the propeller does not, in consequence, become free*so long as the rotary moment M_m of the engine fulfills the CONDITION that

$$M_m > - M \cdot \frac{\theta_m}{\theta} \quad \ldots\ldots\ldots\ldots\ldots (7)$$

the retardation (which only occurs with negative M_m) of the parts of the engine being actually given by $\frac{M_m}{\theta_m}$.

According to HOFF, however, θ_m is 0.020 without the dynamometer, with the dynamometer, unfavorably calculated, 0.020 kgm/sec.², so that therefore the result must be that:

$$M_m > - M \cdot \frac{0.517}{0.026} = - \frac{1}{20} \cdot M \quad \ldots\ldots\ldots\ldots (7a)$$

that is, a CHANCE OF PRESSURE up to - 1/20 of the ordinary rotary moment and in the present instance up to $\frac{-45.6}{20} = - 2.3$ kgm. may be assumed. This does not even occur in the case of the normal 4-cylinder engine in ORDINARY WORKING,** far less in the

* We shall not take into consideration the period during which the propeller becomes entirely free.

**Compare O. WINKLER'S "Entwerfen von leichten Benzinmotoren, insbesondere von Luftfahrzeugmotoren," Berlin W.62, 1914, p.82 etc. (Design of light gasoline engines, especially of Airplane Engines.)

6- and 8-cylinder engines, in which the ratio of the masses is more favorably located.

If one of the cylinders should cease working, there is a strong variation of pressure in the 4-cylinder engine, less in the 6- and 8-cylinder, and none whatever in the 12-cylinder engine. In the first instance, - which is certainly less important - there is no lifting in any case; in the modern 6- and 8-cylinder engines, on the other hand, it does not generally occur. This has also been proved by experience.

In throttling down strongly, however, such high suctional resistance may occur in all engines that lifting is unavoidable. In general, condition (7) is maintained. EXPERIMENTS* made with the dynamometer hub also show that it does not usually derange the smooth running of the engine. It is only when there is rapid throttling that it flaps and in gliding flight with the engine stopped, when the propeller comes into resonance with the number of revolutions of the engine, With an ordinary number of revolutions, however, there is little risk of the rapid vibration of the propeller and crankshaft system and of the consequent critical number of revolutions, if the following conditions be observed:

The dynamometer is not only a SHORT CIRCUIT DRIVING COUPLING, but also an ELASTIC COUPLING. It will therefore have more or less effect on the vibration according to the nature of the

* Compare O. ENOCH'S article in No. 19 of the "Zeitschrift für Flugtechnik und Motorluftschiffahrt."

oil, of the tubular piping, etc. Shocks might actually, in one case,* be avoided by the installation of additional piping. The DANGER OF RESONANCE must therefore always be taken into consideration at the time of installation, as also in the case of engines constructed without a dynamometer.

SUMMARY: Every measuring device influences, by its own presence, the process that it is intended to measure. The function of the art of measuring is that of reducing such effect as far as possible.

This condition hasbeen fulfilled by the dynamometer, at all events in ordinary working, because it leans on the needle of the capsule for rotary moment at the commencement of retardation until (in one case)

$$\frac{d\,n}{d\,t} = -\frac{M_o}{\theta} \cdot \frac{30}{\pi} = -840 \text{ r.p.m./sec.} \qquad (1a)$$

thus producing the flywheel effect of the ordinary fixed propeller.

In case of change of pressure, the negative rotary moments may (in one instance) increase up to 1/20 of the rotary moment of the propeller before the propeller becomes free. In the case of ordinary engines, this generally allows for the cessation of one cylinder without any lifting on the part of the propeller, and without depriving the engine of its flywheel.

Translated by the Paris Office, N.A.C.A.