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UNITED STATES
NAVAL POSTGRADUATE SCHOOL

DEPARTMENT OF AERONAUTICS

TECHNICAL NOTE

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ELECTRIC DRIVE FOR CIT

AXIAL-FLOW TEST BLOWER

by

M. H. Vavra

UNITED STATES NAVAL POSTGRADUATE SCHOOL
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1. SUMMARY:

This Technical Note shows that the driving power of the Cal. Tech. test blower at an operating speed of 1150 rpm is 24.7 KW for the three-stage bladings that is now installed. Most of the tests at CIT were carried out at a speed of 750 rpm. At this speed the maximum driving power of the blower is about 8 KW. From these data it is evident that a very elaborate torque measuring device and speed control system was necessary for the tests at CIT since the dynamometer consists of a cradled 125 HP D.C. motor.

This dynamometer and the A.C.-D.C. motor generator set will not be transferred from CIT to the USNPGS. To be able to undertake test work at a sound level of about 65 db., and to obtain reasonable measuring pressures, it was decided to use an 1150 rpm, 3 pole A.C. motor for the drive of the blower, which, by means of resistances in the rotor circuit, is capable also of operating at 75% of normal speed, or about 865 rpm.

The test blower will be used in the future to test so-called impulse bladings which have a higher power requirement than the bladings presently installed. It is shown that the power to drive such bladings will not be in excess of 45 KW at 1150 rpm.

The test blower will be installed in one of the test cells of the so-called compressor laboratory. In these cells there is available about 150 KVA A.C. at 480 volts. Thus, the driving motor of the test blower must have a power of 60 HP at 1150 rpm. At a speed of 75% of 1150 rpm, or at about 865 rpm, the power necessary to drive the compressor is about 26 HP.

The mass moment of inertia of the rotor of the blower was found to be about 2.6 lb-ft sec.^{2}. For an assumed mass moment of inertia of the motor rotor of 3.6 lb-ft sec.^{2}, the starting time was found to be about 3.5 seconds, if the discharge valve of the blower is closed partially. These investigations show that no special requirements are imposed on the starter of the 60 HP motor.

The torque delivered by the motor will be measured by a torquemeter. It can be either of the electronic type which measures the phase angle between a rotating member that is not twisted and one that transmits the power, or a mechanical type that measures the torsional deflection of a quill shaft.

2. INTRODUCTION:

The test blower described in Ref. 1 is being sent to the Propulsion Laboratory of the Postgraduate School by action of the Office of Naval Research. At the California Institute of Technology this test blower was driven by a cradled 125 HP D.C. dynamometer with power supplied by a motor-generator set. Ref. 3 shows that it was necessary to install an elaborate electronic speed controller to maintain constant motor rpm over extended periods of time.

Since the D.C. dynamometer and the MG. set will not be transferred to the School it is necessary to provide for an electric drive of the test blower. Appendix VI of Ref. 1 shows that the noise level of the compressor at 1500 rpm was 102. db. on an average, with a maximum of 110 db. at a frequency of 777 Hz. This peak is due to the rotor blades passing through the wakes of the stator blades. It is stated in Ref. 1 that this noise level is bothersome but not unbearable. However, at a speed of 750 rpm, at which most of the test work was carried out at CIT the noise problem was not an acute one. Since the forces acting on the blade are proportional to the square of the rpm of the blower, it is anticipated that the following average sound levels will occur at different operating rpm:

at 1500 rpm	102 db.
at 1200 rpm	65 db.
at 900 rpm	37 db.
at 750 rpm	25 db.

At 1200 rpm the noise level of 65 db. is permissible for test work.

Because most of the tests at CIT were carried out at 750 rpm of the compressor, and to avoid costly electric equipment and speed control devices, it has been decided to drive the test blower with an A.C. electric motor and to measure the torque between the motor and blower by means of a commercially available torque meter. To reduce the noise level and the cost of the electric equipment it was decided to use a 3-pole motor with a speed of about 1150 rpm. Fig. 50 of Ref. 2 shows that the Reynolds number effects between speeds of 1150 rpm and 1500 rpm are small, hence the usefulness of the test data will not be impaired because of the chosen fixed operation speed.

The purpose of this study is to establish the necessary power for the chosen compressor speed, and to establish the necessary characteristics

of the starting equipment. The blower will be installed in the open test cell of the so-called Compressor building of the Propulsion Laboratory. Available at this cell is 225 Amp., 480V, 3-phase A.C., wired to a receptacle with a plug that is interlocked by a 225 Amp. circuit breaker. The available power is therefore (225) (480)√3/1000 = 187 KVA, or about 150 KW.

3. MAXIMUM POWER REQUIREMENTS:

The test blower consists of three stages with a hub diameter D_i = 21.6 in., and a tip diameter D_o = 36 in.. In Ref. 2 the test data obtained by CIT are presented with the following dimensionless coefficients:

$$\bar{\varphi} = \frac{V_m}{U_o} = \frac{\text{average through-flow velocity}}{\text{rotor tip speed}} \tag{1}$$

$$\bar{\Psi}' = \frac{\Delta P}{\frac{\rho}{2} U_o^2} = \frac{\text{total pressure rise per stage}}{\text{dynamic head of rotor tip speed}} \tag{2}$$

$$\bar{\Psi} = \text{work coefficient} = \frac{\bar{\Psi}'}{\eta} \tag{3}$$

The power required in KW to drive the three stages of the blower is

$$KW = \frac{3\,Q\,\Delta P}{\eta\,(738)} \tag{4}$$

where Q = volume flow rate (ft^3/sec)

ΔP = total pressure rise per stage (lb/ft^2)

With $A = \frac{\pi}{4} (D_o^2 - D_i^2) \frac{1}{144} = 4.524\ ft^2$,

and $Q = A\,V_m = A\,\bar{\varphi}\,U_o$,

$$KW = \frac{3A\,\bar{\varphi}\,U_o\ \bar{\Psi}'\,(\rho/2)\,U_o^2}{\eta\,(738)}$$

For ambient conditions with $\rho = (2.4)\,10^{-3}$ lbm sec^2/ft^4,

$$KW = 22.06 \left(\frac{U_o}{100}\right)^3 \frac{\bar{\varphi}\,\bar{\Psi}'}{\eta} = 22.06 \left(\frac{U_o}{100}\right)^3 \bar{\varphi}\,\bar{\Psi} \tag{5}$$

For a speed of 1150 rpm there is U_o = 180.7 ft/sec at the diameter D_o = 36 in., hence

$$KW = (130)\ \bar{\varphi}\ \bar{\Psi} \tag{6}$$

Test data of CIT are given in Ref. 2, Fig. 46. For the highest values of $\bar{\Psi}$ in Fig. 46,

$\bar{\varphi}$ =	0.25	0.30	0.35	0.40	0.45	0.50	0.55
$\bar{\Psi}$ =	0.62	0.57	0.53	0.46	0.38	0.30	0.22
$\bar{\varphi}\ \bar{\Psi}$ =	0.155	0.171	0.1855	0.184	0.171	0.15	0.121

Hence, for a value of $\bar{\varphi}\ \bar{\Psi}$ of about 0.19 the maximum power required to drive the 3-stage blower at 1150 rpm is about (130) (.19) = 24.7 KW if it is fitted with the present blading.

It is planned at the Postgraduate School to investigate bladings with higher flow coefficients than those of the existing blading. In particular, tests will be undertaken with so-called impulse bladings which are of interest for axial rocket motor pumps. In Ref. 4, pp. 350-352, the velocity triangle of a blading of this type is shown by Fig. 13(7)c, and its calculated performance is shown in Fig. 13(9).

These conditions are supposed to pertain to the hub diameter D_i of the blading. For the CIT blower at 1150 rpm, with D_i = 21.6 in., the peripheral speed U_i at D_i is 108.4 ft/sec.

With the symbols of Ref. 4, there is for 3 identical stages

$$KW = \frac{\varphi\ U_i\ A\ \ 3\ \ \rho\ U_i^2\ \tau}{738} = \frac{3\rho A}{738}\ U_i^3\ \varphi\ \tau \tag{7}$$

For the CIT blower at 1150 rpm,

$$KW = (56.3)\ \varphi\ \tau \tag{8}$$

For the impulse blading ($r^* = 1 + \frac{\tau}{2}$) from Fig. 13(9) of Ref. 4.

φ =	0.8	0.9	1.0	1.1	1.2	1.3	1.4
τ =	0.76	0.73	0.70	0.67	0.64	0.61	0.58
$\varphi\tau$ =	0.61	0.656	0.70	0.737	0.768	0.782	0.81

For $\varphi\ \tau$ = 0.8 the necessary driving power is 45 KW.

It was decided therefore to install a 60 HP motor for the drive of the compressor.

The torque meter must transmit a maximum moment M of

$$M = \frac{(50)\ (738)}{\frac{\pi}{30}\ 1150} = 306.5 \text{ ft-lb.}$$

and should have an accuracy of about $\pm$ 0.3 ft-lb at a transmitted torque of 150 ft-lb.

4. STARTING REQUIREMENTS:

The blower will be started with its discharge partially closed, so that the power requirements at full speed will not exceed 0.65 x 56.3 = 36.5 KW for the impulse blading. Hence the moment $M = M_{BO}$ of the blower at 1150 rpm is about 225 ft-lb. This moment changes with the square of the speed during starting, or

$$M_B = M_{BO} \left[\frac{N}{N_o}\right]^2 = 225 \left[\frac{N}{1150}\right]^2$$

where N_o is the normal operating rpm of the motor.

Assuming that the motor develops a starting torque M_M of 110% of the torque at full load or, $M_M = (1.1)\ (300) = 330$ ft-lb, there is during the acceleration of the blower

$$(I_B + I_M) \frac{d\omega}{dt} = M_M - M_{BO} \left[\frac{N}{N_o}\right]^2 \tag{9}$$

where I_B and I_M are the mass moments of inertia of the blower and the motor, respectively. With $\omega = (\pi/30)\ N$,

$$\frac{d(N/N_o)}{dt} = \frac{30}{\pi N_o} \frac{M_M}{(I_B+I_M)} - \frac{30}{\pi N_o} \frac{M_{BO}}{(I_B+I_M)} \left[\frac{N}{N_o}\right]^2$$

or

$$\frac{d(N/N_o)}{dt} = A - B\ (N/N_o)^2 \tag{10}$$

There are

$$A = \frac{30}{\pi 1150} \frac{330}{(I_B + I_M)} = \frac{2.74}{I_B + I_M} \tag{11}$$

$$B = \frac{30}{\pi 1150} \frac{225}{(I_B + I_M)} = \frac{1.87}{I_B + I_M} \tag{12}$$

The starting time Δt (in seconds) is obtained by integrating Eq. 10 from $N/N_o = 0$ to $N/N_o = 1$,

$$\Delta t = \int_o^1 \frac{d(N/N_o)}{A - B\,(N/N_o)^2} = \frac{1}{2\sqrt{AB}} \ln \left[\frac{\sqrt{AB} + B}{\sqrt{AB} - B} \right] \tag{13}$$

The mass moments of inertia must be introduced with the dimensions $lb\text{-}ft^2/g = lb\text{-}ft^2/32.17$, or in lb-ft sec.^{2}

From the dimensions of Fig. 4 of Ref. 2 the mass moment of the blower rotor was found to be about 1.3 lb-ft sec.^{2}, and the 90 blades of aluminum contribute an equal amount to it, hence,

I_B = 2.6 lb-ft sec.^{2}

Assuming that the rotor of the motor has a diameter of 15 in., an axial length of 12 in., and a weight of 500 pounds, there is

I_M = 3.6 lb-ft sec.^{2}

From Eq. 13 the starting time of the motor is then 3.3 sec. Hence, no special requirements seem necessary for the starting of the motor.

5. REFERENCES:

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Axial
Flow
Test
Blower
Power
Compressor
Speed
Starting
Equipment
Characteristics

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