TOSHIBA

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Inverter application manual

Energy-saving effect with inverter driving for the control of Fans and pumps

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1. Introduction

• Why does a motor drive with inverter allow energy saving?

The damper is used for lowering the air capacity or flow of the fans or pumps operated at a constant speed.

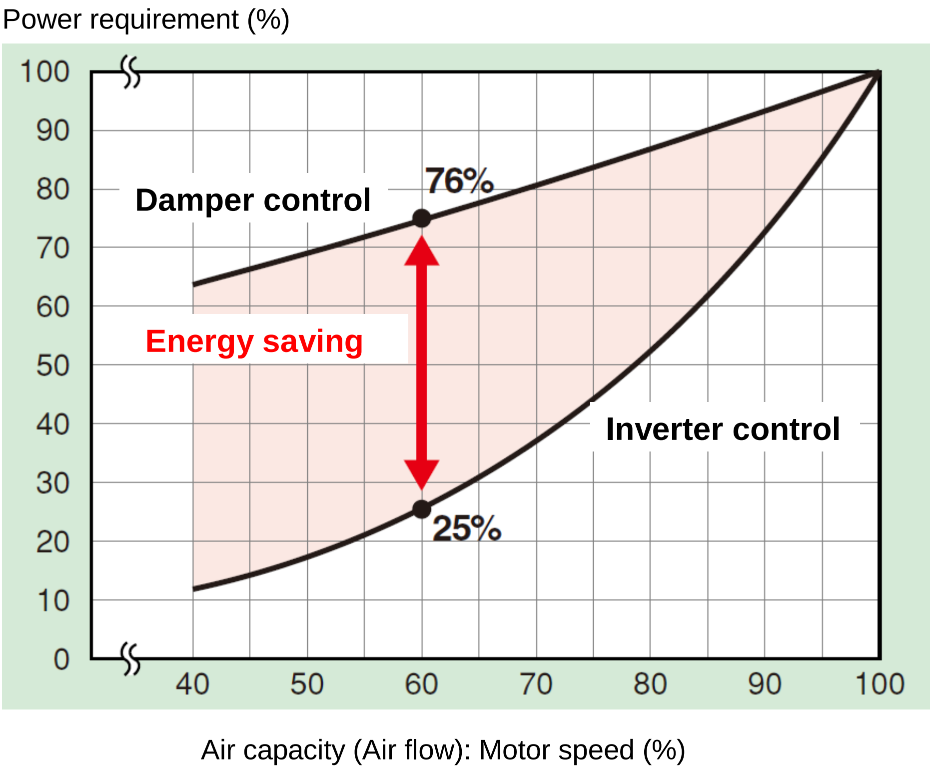
In this case, because of commercial operation, the speed of motor is constant. Therefore, the motor power does not change so much as curve ①, relative to the load variation due to controlled damper.

On the other hand, when the speed is decreased in order to reduce the air capacity or flow of fans or pumps, the motor power will extremely drop because it is ideally in proportion to the cube of speed as described in item ②.

Therefore, the output can be lowered to the minimal level by controlling the speed with inverter drive.

For the energy-saving effect, the greater the variation of air capacity or flow becomes the larger effect it is expectable to have. However, there is no effect with a constant or slightly-changed (approx. 95~100%) air capacity or flow.

Relation between the air capacity or flow and the power
(in case of speed control)



Note) The upper figure shows power requirement. It is necessary to consider efficiency.

2. Energy-saving effect due to flow and pressure control

Fig. 1 is a graph of relation between pump flow Q and discharge pressure (head) H, Q-H characteristic.

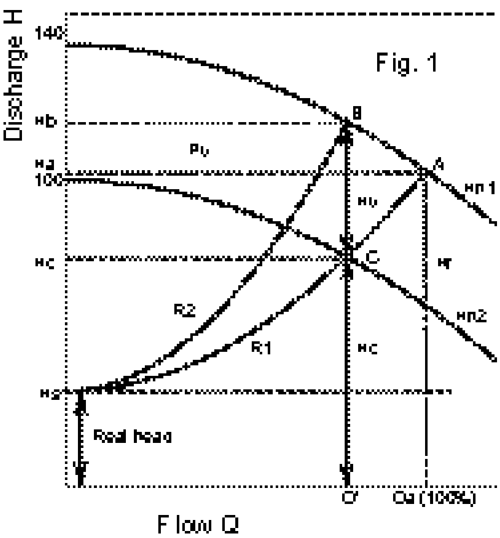
Hn1 is a characteristic curve at the rated speed. Node A with duct resistance curve R1 indicates the rated capacity.

(Rated discharge pressure-equivalent flow: Qa)

While the duct resistance increases almost in proportion to the square of flow Q with real head Hs as reference, it is also raised by stopping down a damper on the discharge side (R1 $\rightarrow$ R2).

Pump shall be operated at the node between these two curves: pump characteristic curve and duct resistance curve.

In order to decrease the flow from Qa to Q', the following procedure shall be performed:



1) Flow control by opening/closing the damper
   By stopping down the damper to increase the duct resistance curve from R1 to R2 and move it to node B with characteristic curve Hn1, flow Q' will be achieved and the discharge pressure will be raised from Ha to Hb.
2) Flow control due to controlled speed
   Because the damper is not controlled, the duct resistance is R1 only. However, by reducing the speed to decrease the pump characteristic curve from Hn1 to Hn2, node C-equivalent flow Q' will be obtained.
   When the flow is lowered from Qa to Q', the discharge pressure is simultaneously decreased from Ha to Hc.

[Shaft power difference]

Shaft power difference between the damper control and the control of speed is as shown below:

Pump shaft power P= $\dfrac{K \times Q \times H}{\eta}$. where, K: constant; η : pump efficiency

Therefore, the shaft power of the pump being operated at point B in fig. 1 can be obtained as follows:

$$Pb = \frac{K \times Q' \times Hb}{\eta} = \frac{K \times Q' \times Hc}{\eta} + \frac{K \times Q' \times Hv}{\eta}$$

The shaft power of the pump being operated at point C can be acquired as follows:

$$Pc = \frac{K \times Q' \times Hc}{\eta}$$

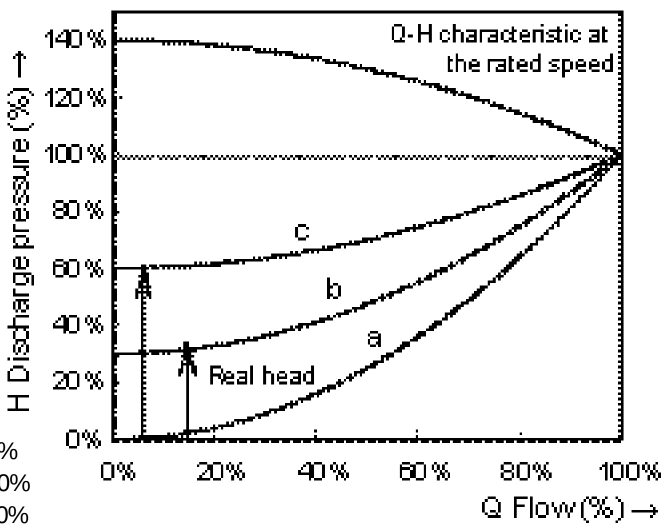
Accordingly, the shaft power difference is calculated as Pb-Pc= $\dfrac{K \times Q' \times Hv}{\eta}$ and the netted area (Pv) as shown in fig. 1 indicates the differential shaft power, energy saving.

2.1. Calculation formula (flow control)

Assuming the shut-off pressure to be 140% of rating in fig. 1, this pump characteristic can be expressed in the following formula: $Hp.u=1.4-0.4Qpu^2$. P.u: Indication of ratio (per unit)
Similarly, based on the mathematization of duct resistance curve, Rp.u per real head is calculated as follows:
(Respective duct resistance curves are as shown in fig. 2.)

a:$Ra=Qp.u^2$
b:$Rb=0.3+0.7Qp.u^2$
c:$Rc=0.6+0.4Qp.u^2$

Fig. 2



Assuming the pump efficiency to be constant, the differential shaft power can be expressed as follows:

$=Pn\times(Hp.u-Rp.u)Qp.u$
Pn: Rated shaft power (kW)

Assigning expressions to the above equations Hp.u and Rp.u, respectively, to be fixed, the differential shaft power, energy saving: Pe, per duct resistance curve relative to flow Qp.u can be expressed as follows:

a:$Pe=Pn\times1.4(1-Qp.u^2)\times Qp.u$(kW) Real head=0%
b:$Pe=Pn\times1.1(1-Qp.u^2)\times Qp.u$(kW) Real head=30%
c:$Pe=Pn\times0.8(1-Qp.u^2)\times Qp.u$(kW) Real head=60%

* In case of fan blower, curve a shall be used.
Pn: Rated shaft power (kW); Qp.u: Ratio of average engaged capacity to the rated capacity
Real head: Proportion to the rated pressure
With different shut-off pressure or real head, the result can be obtained by assigning values in the following equation:
$Pe=Pn\times(Hm-Hx)(1-Qx^2)\times Qx$(kW)
Hm: Shut-off pressure (pressure with capacity 0); Hx: Read head; Average capacity

In order to calculate the saved electricity charge, the above-obtained value (kW) shall be multiplied by the annual operating time and the watt-hour rate.

2.2. Calculation formula (pressure control)

With constantly-controlled discharge pressure of pump, by replacing Rp.u under flow control with the set pressure Pp.u (% to the rated pressure) to assign values of 1, 0.7 and 0.4 in case that the shut-off pressure is 140% of rating, the following equations are obtained. The lower the set pressure gets, the greater the energy-saving effect becomes:

$Pp.u(1) = Pn \times (0.4-0.4Qp.u2) \times Qp.u(kW)$
$Pp.u(0.7) = Pn \times (0.7-0.4Qp.u2) \times Qp.u(kW)$
$Pp.u(0.4) = Pn \times (1-0.4Qp.u2) \times Qp.u(kW)$

With different shut-off pressure or set pressure, the result can be calculated by assigning values to the following equation:

$Pe = Pn \times \{(Hm-Px)-(Hm-1) \times Qx^2\} \times Qx(kW)$

Hm: Shut-off pressure (pressure with flow 0); Px: Set pressure; Qx: Average flow

In order to calculate the saved electricity charge, the above-obtained value (kW) shall be multiplied by the annual operating time and the watt-hour rate.

3. Material 3 (calculation formula and data)

1. Speed of motor (min^{-1}) (synchronous speed)

$$= \frac{120 \times \text{Frequency(Hz)}}{\text{P(Number of motor poles)}}$$

2. Input electric power (kW) in case of driving with direct commercial power input

$$= \frac{\text{Output capacity of motor (kW)} \times \text{Load factor}}{\text{Motor efficiency}}$$

3. Input electric power (kW) in case of driving with inverter

$$= \frac{\text{Output capacity of motor (kW)}}{\text{Motor efficiency} \times \text{Inverter efficiency}} \times \left(\frac{\text{Revolving speed}}{\text{Rated revolving speed}} \right)^3$$

* Speed = Speed in case of driving with inverter
* Rated speed = Speed of engaged motor in case of driving with direct commercial power supply

4. Shaft power requirement P (kW)
   1) In case of fan

$$P = \frac{Q \times H \times K}{6120 \times \eta \times 9.81}$$

   * Q : Air capacity (m^3/min)
   * H : Wind pressure (Pa)
   * K : Coefficient
   * η : Efficiency (%)

   2) In case of pump

$$P = \frac{(1.1 \sim 1.2) \times Q \times H \times \gamma}{6.12 \times \eta}$$

   * Q : Pump discharge (m^3/min)
   * H : Total head (m)
   * γ : Mass per unit cubage of fluid (kg/l)
   * η : Efficiency (%)

5. Inverter efficiency (%)
   90~96% in general: Depends on inverter capacity and model, etc.

変 更 記 録　ＲＥＶＩＳＩＯＮＳ

変更回数 REV.	変更発行日 REV. ISSUED	変更箇所・変更内容 CHANGED PLACE AND CONTENT	承 認 APPROVED BY	調 査 CHECKED BY	担 当 PREPARED BY
（ 0 ）	記録なし	初版発行　INITIAL ISSUED	記録なし	記録なし	記録なし
（ 1 ）	2013-2-7	P.2：風量・流量と所要動力の関係図を変更、注記追記 P.6：ファン所要動力　計算式修正 133.322⇒9.81	岡田 2013-2-7	山本/小森 2013-2-7	川上 2013-2-6
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