Baldor Basics: Applications

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Former Baldor motors expert Edward Cowern PE, is a name known and respected by many in the electric motor industry. During his tenure at Baldor, Cowern — now enjoying his retirement — was tasked with producing a number of motor- and basics-related tutorials. The tutorials were primarily in response to a steady flow of customer questions regarding motors and applications. Today's customers continue asking questions and seeking answers to address their various motor-related concerns. We hope you find these articles useful and would appreciate any comments or thoughts you might have for future improvements, corrections or topics.

Fans, Blowers and Other Funny Loads

A family of motor applications that tend to confuse people who are not regularly involved with them, is that of variable torque loads. These loads represent a high percentage of motor requirements, so it is desirable to have a little extra knowledge of the mysterious aspects of these loads. First, variable torque loads are fans, blowers, and centrifugal pumps. In general fans and blowers are moving air but centrifugal pumps can be moving many kinds of liquids including water, petroleum products, coolants, etc.

There are two mysterious characteristics that these loads have. The first is the way they act when the speed is changed. The rules that cover these characteristics are called the "affinity laws." In order to simplify we will discuss only the performance of these loads when they are applied to systems where the load is not changing. For example, we can discuss a pump arrangement as shown (Fig. 1); this is a pump circulating chilled or hot water through a closed system. What we find is that the torque required to drive the pump goes up as a squared function of speed ($Speed^2$). Thus, increasing the speed causes the torque required by the pump to go up, not directly with speed, but in proportion to the change of speed squared. For example, if we change the speed from 1,160 to 1,760 rpm, the torque required will go up by the ratio of $(1,760 \div 1,160)^2$. This would mean that the torque required would go up by 2.3 times — to 230% of the original value. Also, since horsepower (HP) is based on speed times torque, and the speed has increased by 52%, the new value of HP would be 2.30×1.52, or almost 350% of the HP required at the original speed.

The dramatic increases in the horsepower required to drive these loads when speed increases is a little difficult to understand, but it is very important. It is also important because small decreases can result in great energy savings. For example, decreasing the speed of a variable torque load by only 20% will result in a driving energy reduction of nearly 50%. This, obviously, has big importance when conservation is considered. It also accounts for the tremendous market that exists for variable frequency drives operating variable air volume (VAV) systems used in heating, ventilating, air conditioning and variable speed pumping used in similar systems.

The second puzzling thing that occurs with variable torque

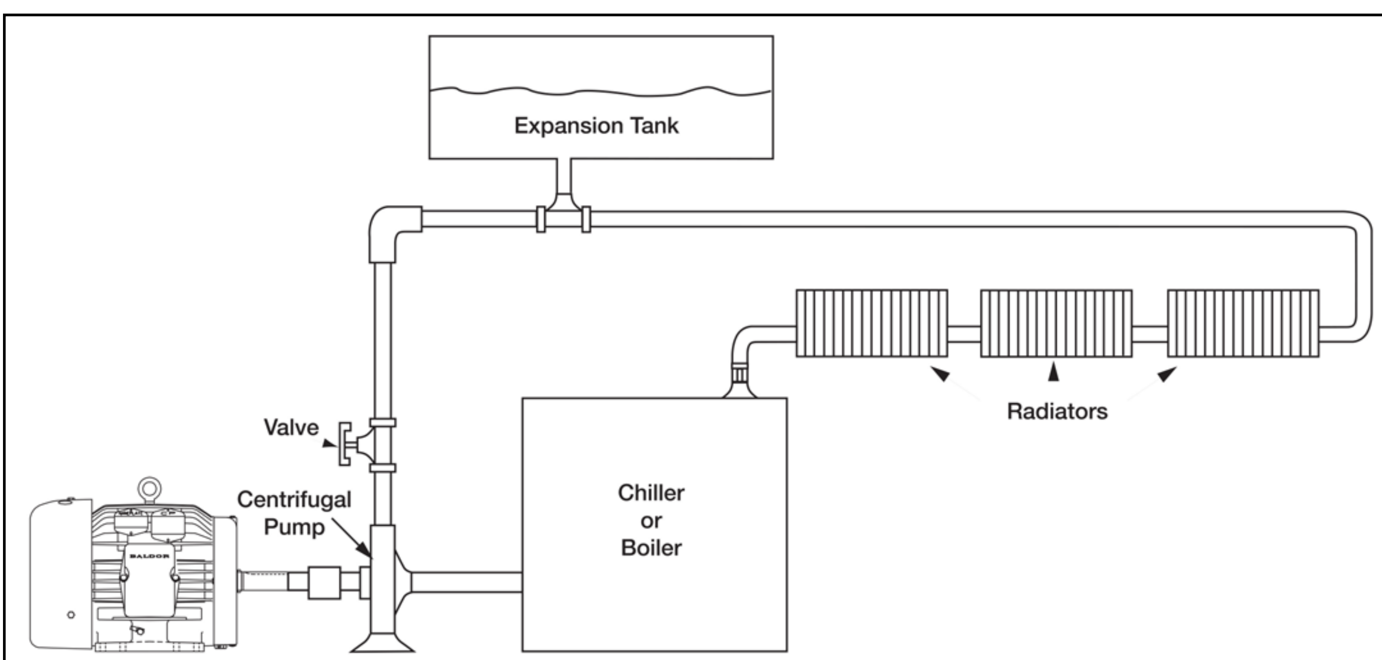

Figure 1 Pump arrangement circulating chilled or hot water through a closed system.

loads is that the motor load actually decreases as the output or input to the blower or pump is blocked off or restricted. This would be the situation in Figure 1, as the valve is closed. The reverse of this is that motor load increases dramatically as restrictions are removed. As an example of this, I once had a call from a motor user who had burned out a motor driving a blower on a heating system. The motor was driving a blower that drew air through a filter and fed it to a ducted distribution system. When I asked if there had been any changes in the system he said, “Well, we extended the ducts into another room and cut the end off to let the air flow, but that would have made it easier for the motor not more difficult.” When I told him that the opposite was true he couldn’t believe it. It defies good judgement to think that adding a restriction to the output of the blower would decrease the motor load. If you don’t believe it, here’s a simple test. Take a vacuum cleaner and listen to it carefully while you alternately open and close the suction. At first you might think that the “heavier” noise is the motor straining when the suction is the greatest, but if you listen more carefully you will notice that the pitch of the motor goes up when the suction is closed. What this means is that the load is being reduced on the motor and it speeds up. If you still don’t believe, you can do the same test but with an ammeter on the motor. What you will find is that the amps drop as the suction level is increased. The same is true of centrifugal pumps. Closing down or restricting the output causes the pump to draw less mechanical power.

Another way of looking at this is when the output of a centrifugal pump or a squirrel cage blower is closed off, the air or fluid inside the housing becomes a “liquid flywheel;” it just spins around with the vanes of the pump or blower. Since there is no new fluid coming in to be accelerated, the only energy needed is what it takes to make up for the friction losses within the housing of the pump or blower. It doesn’t seem to make sense, but that’s the way it is!

As another example, think of fans applied to dust collection systems; the maximum load occurs when everything is as clean as can be. As the filter bags get coated with dust, the back pressure increases and the load on the blower and motor is reduced.

The amount of overloading or underloading that occurs as a result of changes in the “back pressure” on the pump or blower will depend on the specific design of impeller used. Some types of pumps and blowers are designed to be non-overloading, but typically the worst-case loading occurs at the open discharge condition.

Fans and Blowers Summary

When dealing with variable torque loads things are not always as they would seem. If there is some question about how this equipment performs, it is best to contact the equipment manufacturer and discuss the matter.

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Correction

An article in the April issue of *Power Transmission Engineering* — “Baldor Basics: Understanding Torque” — contained several copy editing errors which in several cases led to publishing incorrect formulas for HP (horsepower). None of these errors existed in the Baldor-supplied original material. Our apologies to series author Ed Cowern, ABB/Baldor, and our readers.

The value of the constant changes depending upon the units that are used for torque; the most frequently used combinations are:

$$HP = \frac{T \times S}{5252}$$ T = Torque in lb. ft.
S = Speed in RPM

OR

$$HP = \frac{T \times S}{63{,}025}$$ T = Torque in lb. in.
S = Speed in RPM

OR

$$HP = \frac{T \times S}{1{,}000{,}000}$$ T = Torque in in. ounces
S = Speed in RPM

Rearranging these formulas to obtain torque, we can arrive at the equations:

$$T = \frac{HP \times 5252}{S}$$ T = Torque in lb. ft.
S = Speed in RPM

OR

$$T = \frac{HP \times 63{,}025}{S}$$ T = Torque in lb. in.
S = Speed in RPM

OR

$$T = \frac{HP \times 1{,}000{,}000}{S}$$ T = Torque in in. ounces
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The online version of the article has been corrected. You can download it at *www.powertransmission.com/articles/0417/Baldor_Basics:_Understanding_Torque/*

RMS Horsepower Loading

There are a great many applications — especially in hydraulics and hydraulically-driven machines — that have greatly fluctuating load requirements. In some cases, the peak loads last for relatively short periods during the normal cycle of the machine. At first glance, it might seem that a motor would have to be sized to handle the worst part of the load cycle. For example, if a cycle included a period of time where 18 HP is required, then the natural approach would be to utilize a 20 HP motor. A more practical approach to these types of "duty cycle loads" takes advantage of an electric motor's ability to handle substantial overload conditions, as long as the period of overload is relatively short compared to the total time involved in the cycle.

The method of calculating whether or not the motor will be suitable for a particular cycling application is called the RMS (root mean squared) horsepower loading method. The calculations required to properly size a motor for this type of application are relatively simple and are presented in this paper.

RMS calculations take into account the fact that heat buildup within the motor is very much greater at a 50% overload than it is under normal operating conditions. Thus, the weighted average horsepower is what is significant. RMS calculations determine the weighted average horsepower.

In addition to reducing the size and cost of a motor for a particular application, RMS loading also offers the advantage of being able to improve the overall efficiency and power factor on a duty cycle type of load. For example, when an oversized motor is operated on a light load, the efficiency is generally fairly low, so working the motor harder (with a higher average horsepower), will generally result in improved overall efficiency and reduced operating cost.

In order to use the RMS method of horsepower determination, the duty cycle has to be spelled out in detail (Fig. 1).

In order to determine the RMS loading for the previous cycle, we can use the formula:

$$\text{RMS HP} = \sqrt{\frac{HP_1^2 \times t_1 + HP_2^2 \times t_2 + HP_3^2 \times t_3 + HP_4^2 \times t_4 + \cdots HP_x^2 \times t_x}{t_1 + t_2 + t_3 + t_4 + \cdots t_x}}$$

The easiest way to approach this type of calculation is to make several columns, as shown (Fig. 2).

Figure 2 Method used in determining previous-cycle RMS loading.

Step	Horsepower	HP^2	Duration (Seconds)	$HP^2 \times$ Time
1	3.0	9.0	3	27.0
2	7.5	56.3	10	563.0
3	2.5	6.3	12	75.6
4	12.5	156.3	3	468.8
			28	1134.4

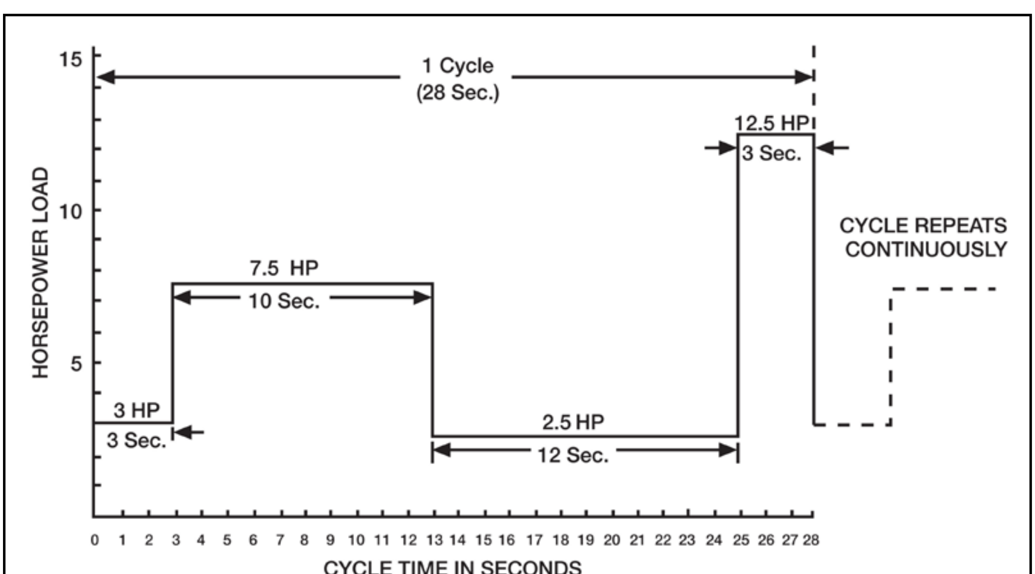
In this case, the total time of the cycle is 28 seconds and the summation of horsepower squared times time for the individual steps in the cycle is 1,134.4. When inserted into the equation, the RMS horsepower comes out to be:

$$\text{RMS HP} = \sqrt{\frac{1134.4}{28}} = \sqrt{40.5} = 6.4$$

At first glance, it appears that a 7½ HP At first glance, it appears that a 7½ HP motor would be adequate to handle the loading required by this duty cycle. One further check has to be made and that is to determine if the motor has adequate pullout torque (breakdown torque) to handle the worst portion of the duty cycle without stalling. In this case, you would have to refer to the manufacturer's data for the motor and determine the percent of pullout torque that is available.

An additional safety factor should be used because the pullout torque of the motor varies with the applied voltage. In fact, the pullout torque varies in relation to applied voltage squared. Thus, when the motor is running on 90% of rated voltage the amount of pullout torque available is only .9 × .9 or approximately 80% of the value that it has at full rated voltage. For this reason, it is never safe to use the full value of the pullout torque to determine if the overload can be handled. As a rule of good practice, it is wise not to use more than 80% of the rated pullout for a determination of adequacy.

In this case, **referring to the Baldor Engineering Data Section on www.Baldor.com**, we would find that a 7½ HP, open drip proof motor with a catalog number M3311T, has



Step	Horsepower	Duration (seconds)
1	3	3
2	7.5	10
3	2.5	12
4	12.5	3
Repeats continuously.		

Figure 1 Using RMS method of horsepower determination requires that duty cycle is spelled out in detail (Fig. 1).

a breakdown torque of 88.2 ft. lbs. and a full load operating torque of 22.3 ft. lbs. Thus, the actual pullout torque is 395% and utilizing 80% of this value, we would find that the available, safe pullout torque would be 316%.

For the duty cycle shown, the required pullout torque percentage can be determined by the ratio of maximum horsepower to rated horsepower as follows:

$$\%\,\text{Pullout torque required} = \frac{12.5\,(\text{Max. HP Point}) \times 100 = 167\%}{7.5\,(\text{Selected HP})}$$

Since the available pullout torque at 90% of rated voltage is 316%, this 7½ HP motor would be more than adequate to handle this application.

The previous formula and example can be used for applications where the duty cycle repeats itself continuously, without interruption. When a duty cycle involves a period of shut-off time, a different formula is used. That formula is shown below.

$$\text{RMS HP} = \sqrt{\frac{HP_1^2 \times t_1 + HP_2^2 \times t_2 + HP_3^2 \times t_3 + HP_4^2 \times t_4 + \cdots HP_x^2 \times t_x}{t_1 + t_2 + t_3 + t_4 + \cdots t_x}}$$

Where,

t_s = number of seconds that motor is stopped

C = 3 (open drip-proof motors)

or,

C = 2 (totally enclosed motors)

This formula is the same as the previous one but it is modified to reflect the fact that during the non-operating (motor is at standstill) time, it also loses its capability of cooling itself.

The total amount of time for which RMS loading can be adequately calculated would depend somewhat on the size of the motor but, in general, it would be safe to utilize this method for duty cycles that total less than 5 minutes from start to finish (of one complete cycle). If the total time is beyond 5 minutes, then the application should be referred to the motor manufacturer for more detailed analysis.

Summary

RMS horsepower loading is a very practical way to reduce motor horsepower requirements on cycling loads. With reduced motor horsepower also come a reduction in physical size and a reduction in initial cost, along with somewhat improved efficiency and reduced operating costs. If the selection procedure is handled carefully, you can expect to get very good performance and reliability from the completed unit.

On servomotors and other adjustable speed applications, similar calculations are frequently made. In these cases armature amperes or required torques are substituted in place of horsepower. The resulting RMS amperes or RMS torque requirement is then compared to the motor's continuous and peak ratings to determine adequacy. **PTE**