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IT TAKES MORE THAN JUST CURRENT AND OPERATIONS TO SPECIFY A RELAY

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INTRODUCTION

Probably the most widely used but least understood starting device for hermetic motors is a current relay. Literally millions of these are used very successfully every year. In fact, there is a tendency to sort of "take them for granted" and never really try to understand why they work and, on that rare occasion, why they don't work.

All electro-magnetic relays could be called current relays because they do have electric current flowing through their coils in order to create magnetic fields. For the purposes of this paper however, a current relay is defined as an electro-magnetic relay whose coil is in series with the main winding of a motor so as to carry the same current as the main winding (Fig. 1). The contacts of the relay are in series with the start, or auxiliary, winding so as to make, carry, and break this current. If the motor utilizes a start capacitor then the contacts handle that also (Fig. 2).

CONSTRUCTION

The construction of a typical current relay is shown in Fig. 3. When sufficient current flows in the coil the plunger rises to gather in more of the flux. This movement compresses the spring against the cap, which is crimped on the sleeve. When the compressed spring force overcomes the pull of gravity, the sleeve head pulls up on the bridge assembly, closing the contact circuit. Further movement of the plunger compresses the spring more, increasing the contact force until an equilibrium condition is reached. Decreasing the current in the relay coil reverses this action.

MOTOR CHARACTERISTICS

For a complete understanding of how a current relay performs with a single phase induction motor, it is necessary to examine the motor characteristics, the relay characteristics, and their interactions.

Fig. 4 shows a set of typical motor performance curves which have some effect on relay operation. The torque and main winding current curves are shown at room temperature and at a nominal line voltage. As the winding temperature increases or as the voltage decreases the curves will shift to the left. Since the relay contacts are normally open, the relay must pickup before the start winding can be energized. This means that the current in the main winding, at hot temperature and low voltage, must be sufficient to pickup the relay plunger

RESISTANCE START-INDUCTION RUN SINGLE PHASE MOTOR

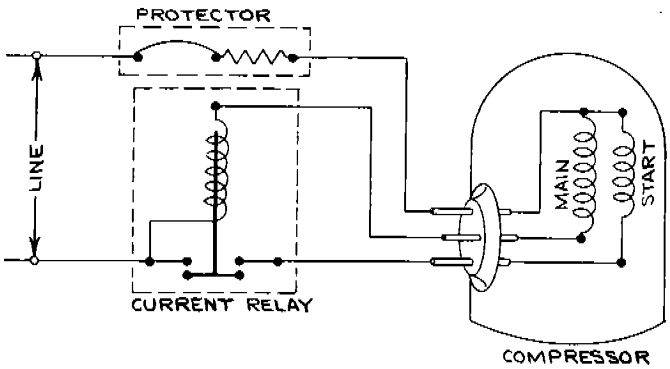

FIG. 1

CAPACITOR START-INDUCTION RUN SINGLE PHASE MOTOR

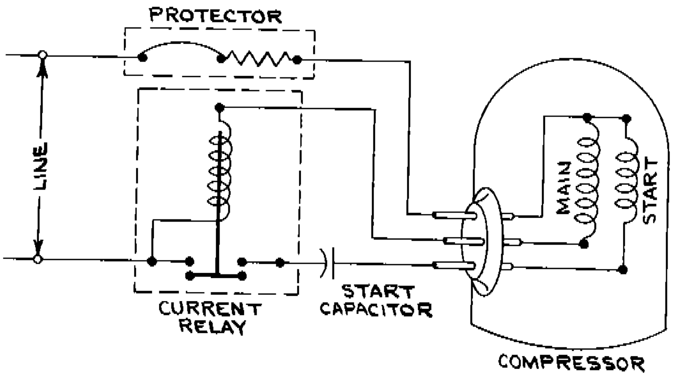

FIG. 2

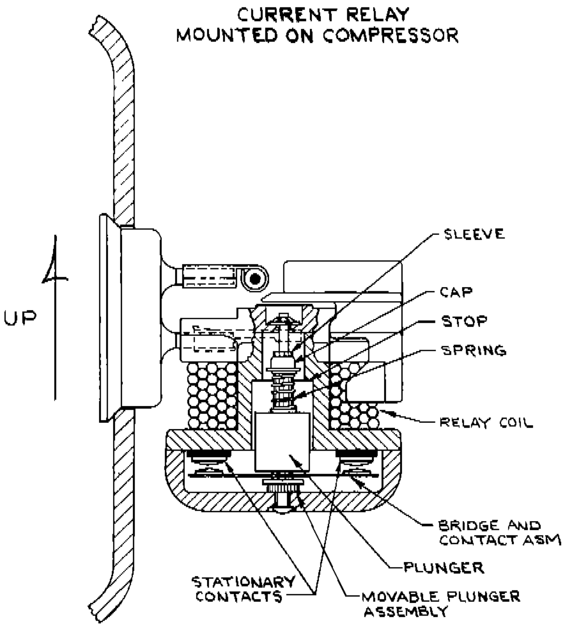
CURRENT RELAY MOUNTED ON COMPRESSOR

FIG. 3

assembly. As the motor approaches running speed the main winding current decreases. If the relay is to dropout and disconnect the start winding, the main winding current must drop below the dropout calibration of the relay with extreme conditions of voltage, temperature, and torque. Once the contacts open, the main winding current will normally decrease even further to the curve showing that current vs. speed without the start winding.

RELAY PULL AND LOAD CURVES

The relay characteristics can best be understood by examining a set of pull and load curves (Fig. 5). For a given number of turns on a specific relay design, a family of pull curves can be plotted. Force to move the plunger is plotted against the position of the plunger for each of several currents. These force curves all pass through zero at the magnetic center of the coil; reach a maximum at some distance away; and become asymptotic to zero as the distance becomes large.

A typical load curve is also shown in the same figure. These are the forces which oppose the pull of the magnetic field but for comparison they are shown in the same direction. In other words, the excess of the pull above the load is what is available to accelerate the plunger. In order to pickup the plunger assembly the pull must be above point 'A' on the load curve. In order to dropout the plunger assembly, the pull must be below point 'B' on the load curve. These pull curves are drawn with the assumption of a steady current. The oscillations due to alternating current will be discussed later in this paper.

Some observations that can be made from these curves are:

1. Operating on a relatively flat portion of the pull curve means a narrow differential relay.
2. Increasing the weight of the plunger assembly requires more current but a steeper pull curve is available.
3. The static weld breaking force is equal to the weight of the plunger assembly.

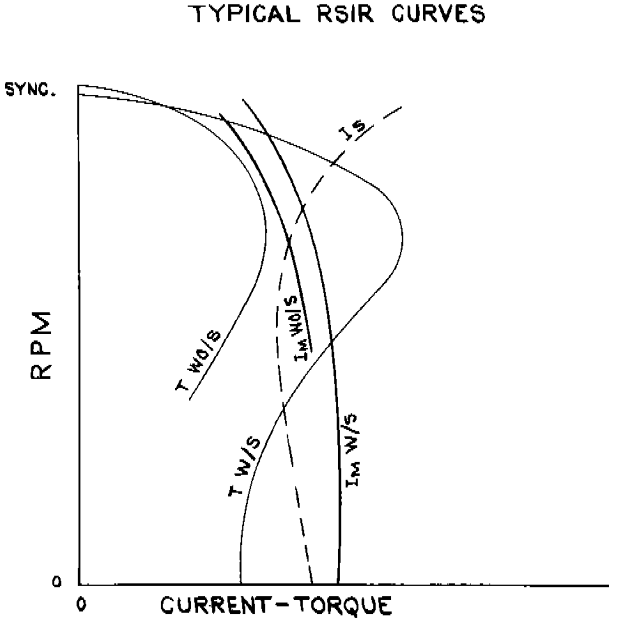
TYPICAL RSIR CURVES

FIG. 4

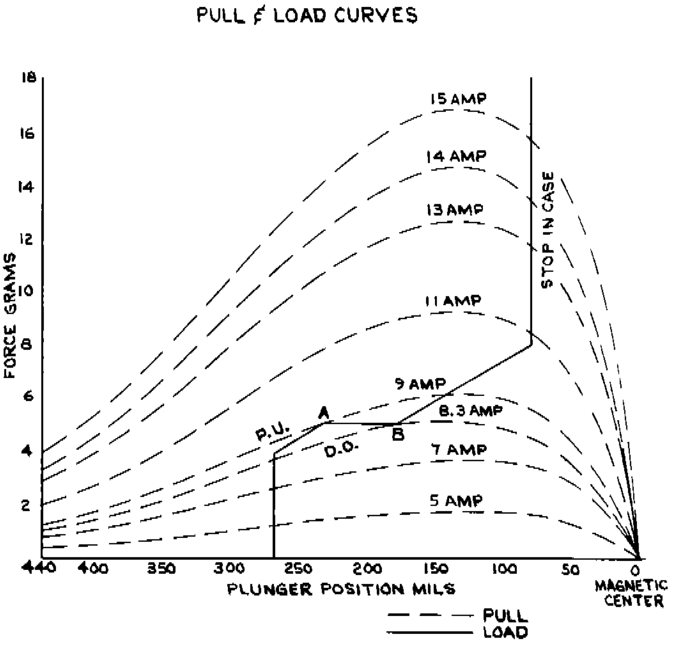
PULL & LOAD CURVES

FIG. 5

4. Contact gap and differential are directly related.
5. Contact force is a function of the gradient of the plunger assembly spring and the shape of the pull curve.

DYNAMIC OPERATION

Although the pull and load curves are very useful in understanding relay operation, they do not tell the whole story about the operation of a current relay applied to a hermetic compressor. Referring back to Fig. 3 one can see that the plunger assembly is a fairly complicated spring-mass vibrating system. The plunger and the bridge assemblies are independent masses coupled by a spring. The movement of the plunger is restricted between the top of the bridge and the upper stop in the case. Since the complete operation of pickup and dropout is completed in a fraction of a second, the plunger is never completely still during this sequence. The instantaneous position and force vectors on the plunger become more important than the steady state conditions.

Fig. 6 shows a plot of contact force (positive force is shown down) vs. time for three different voltages on a typical motor-relay system. It also shows how dynamic weld breaking force is affected by rate of decay of coil current. Another way to look at this dynamic operation of the plunger assembly is to see the momentum of the plunger as shown in Fig. 7. Momentum may be either positive or negative depending on the velocity vector at that instant. Differential equations of motion could be derived to fit particular situations but the intent of this paper is to point out typical causes and effects rather than specific application conditions.

In addition to the oscillations of the spring-mass system there are two major sources of excitation--magnetic fields and external vibration. When a motor is called upon to start, current starts flowing through the relay coil creating an alternating magnetic field. The instantaneous field strength is a function of the magnitude of the coil current, the portion of the sine wave it is on, and the position of the plunger.

At locked rotor there is an excess of current in the relay coil above that required for pickup. This current creates a field which has sufficient pull to accelerate the plunger upwards. As soon as the contacts close there are two factors which affect the main winding current. The first factor is that the start winding is energized; the rotor starts turning; and the impedance of the main winding starts changing. Even if the voltage applied to the motor could be held constant, there would be changes in this current. This brings up the second factor which is that the voltage at the motor terminals does not remain constant. When current starts flowing in the start winding it adds vectorially to the main winding current to increase the line current. This increased line current creates an added voltage droop as a function of the line impedance.(2) Reduced line voltage results in reduced main winding current and reduced torque. The Fig. 8 oscillogram shows what happens to the main winding current as the start winding comes in and the motor accelerates to running speed. As the motor approaches its running speed the main winding current begins to decay. This rate of decrease is important in the operation of a current relay and is determined by such factors as:

1. Characteristics designed and built into the motor.
2. Torque available vs. that required by the load.
3. Line voltage.
4. Winding temperature.

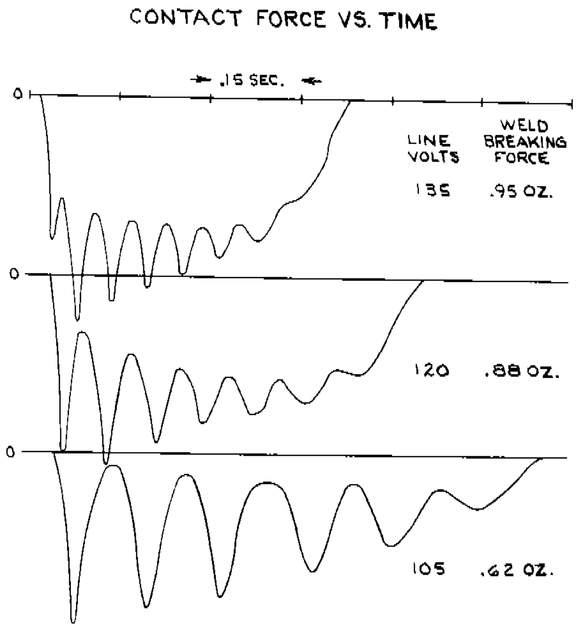

FIG. 6

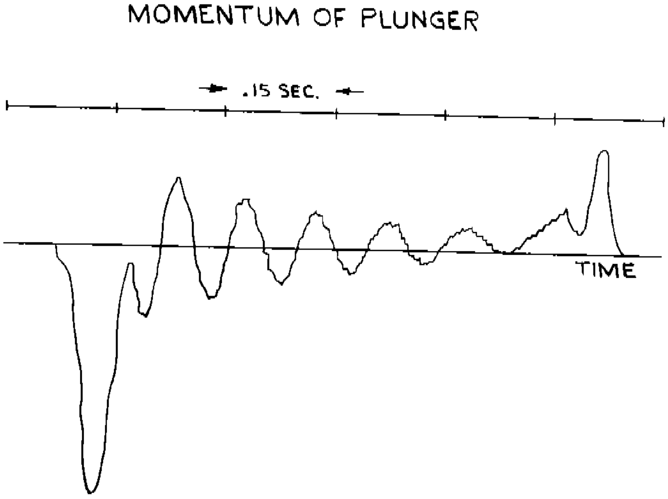

FIG. 7

CHATTER CAUSED BY LINE DROOP

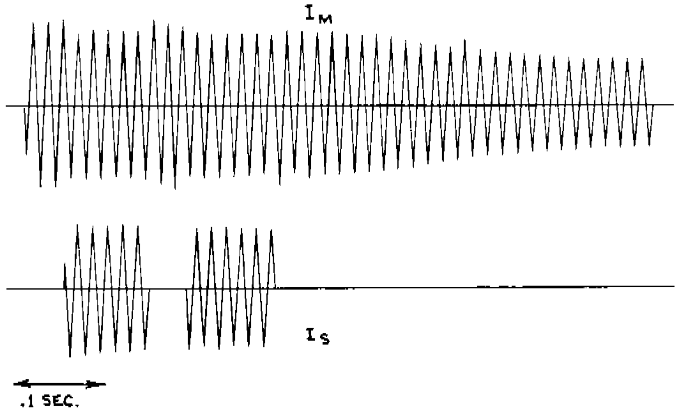

FIG. 8

The relay plunger's position is determined by the magnitude of the magnetic field but its motion is affected by the change in the field.

External vibration sources also contribute to the excitation of the plunger assembly. This is a variable whose amplitude and direction is a function of whether the compressor is a rotary or piston and how the motor is suspended in the shell. Initial starting exerts a force on the relay mounting during the time the plunger assembly is moving. Any of the other factors, such as excess oil, which cause compressor vibrations will also shake the relay.

During the fraction of a second that a current relay is operating it is subjected to the vibration system of its own plunger assembly with the excitation of a changing magnetic field and external vibrations transmitted through its mounting. Normally the system works faultlessly, but there are some combinations of conditions that are marginal and deserve close scrutiny.

DYNAMIC SYSTEM PROBLEMS

Most of the relay problems fall into one of three categories. These are: erratic pickup, erratic dropout, and contact welding. The effect of these problems will be a variable depending on the tolerance of other components on the system and the cause of these problems can be completely remote from the relay itself.

Pickup

Erratic pickup is usually characterized by premature re-opening of the contacts and disconnecting the start winding with a resultant loss of torque. The most common source of this problem is a relatively high impedance line between the power line and the motor terminals. This includes the wiring harness, particularly the switches and terminal connections. The sudden decrease in main winding current just when the start winding is energized may be sufficient to cause the relay to dropout before the motor begins to pick up speed. As soon as the contacts open the current increases again and the relay picks back up. This could be repeated several times depending on how close the relay pickup calibration is to the minimum current available and how much excess torque the motor has over the load requirements. Low voltage, high temperature, and high relay calibration aggravate the problem. Measurements have been made which show as much as one ohm impedance in some refrigerators and house wiring. If a 15 amp start winding current is switched in on such a circuit there would be approximately 15 volts drop at the main winding terminals. A 10% decrease in main winding current due to line voltage droop is not too unusual and this could exceed the dynamic differential of the relay. Dynamic differential is defined as that change in coil current required to reverse the motion of the plunger assembly when the contacts just close or just open.

Dropout

Erratic dropout can be caused by several conditions external to the relay itself. One cause would be where the motor is just incapable of accelerating to the speed where the main winding current, while running with the start winding in, is less than the dropout calibration of the relay. This may be because there is not enough knee or bend-over of the current vs. speed curve (Fig. 4). Another reason may be that a combination of load, temperature, and voltage inhibit the required current change. Checking for dropout with a cold motor and high voltage does not always create the maximum current condition. In the case where a motor is heavily loaded, it could be required to run at a lower speed at low voltage in order to develop enough torque, and consequently draw more current than it would at a higher voltage and higher speed. This is not a common problem but it has been observed.

Referring back to the pull and load curves in Fig. 5 it can be seen that at point 'B' there is a balance between the pull and the load at the dropout point. When the dynamic motion of the plunger assembly is coupled with the oscillating exciting forces a condition could exist whereby the contacts are dancing around with essentially zero contact pressure. If this condition exists for some finite time a small tack weld may be created. This would mean that the pull would have to be decreased further, i.e., the current would have to drop more, in order for gravity to overcome this holding force and open the contacts. The strength of the weld would determine how much additional reduction of current is necessary. External vibration might possibly be helpful or harmful to this condition. It might be enough to break the weld or the arcing contacts may weld tighter.

Welding

Contact welding may occur without causing the compressor to fail or creating a nuisance type service call. Welds can be classified by their relative strength. The weakest weld is a 'run weld' or a 'tack weld' which lasts only so long as the motor is running. As soon as the motor is shut off the plunger no longer has any upward attraction so the full force of gravity is available to break the weld. If the weld does not break when the coil current is reduced to zero, it is classified as the next stronger type, or just 'weld'. The strongest weld is one which does not break after repeated attempted starts and overload trips (arbitrarily set at three times). This is classified as a 'solid weld' and is the ultimate failure.

Another type of contact weld could be the result of a plunger assembly hang-up at the contact kiss position. This is not the fault of the contact action but is usually caused by an excessively high current in the relay coil. This high current could be from a heavy load on the motor causing it to run at a lower speed or from some insulation failure. Whatever the source, the result is an overheated coil which blisters the plastic barrel, binding up the plunger on its next upward stroke.

There is another cause of contact welding that needs to be discussed. This is the one resulting from the use of a current relay on a capacitor start, capacitor run motor. Fig. 9 shows the wiring connections where a current relay and start capacitor might be added to a permanent split capacitor motor to increase its starting capability. There is a finite time delay between when the run capacitor is energized and the closing of the contacts. (Fig. 8) The loop between the two capacitors and the relay contacts is almost a short circuit so, if one capacitor is out of phase with the other when the contacts close a high circulating current is made by the contacts. This acts like a capacitor welder on the contacts. It is not recommended that a current relay be used on this type of application. Even the addition of a bleed resistor on the start capacitor does not solve the problem.

APPLICATION TESTING

In order to determine if a current relay meets the requirements of an application two basic questions must be answered. The first one is "How does the system perform?" and the second one is "How long will it last?"

CAPACITOR START AND RUN
SINGLE PHASE MOTOR

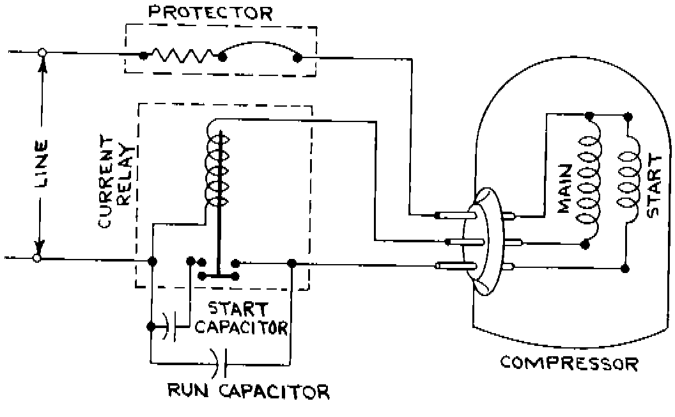

FIG. 9

The best way to arrive at the answer to the first question is by application testing. It is best that this be done on the end product, but if that is not possible, then the effects of the end product should be factored in. Since the action is all over in a fraction of a second, measuring or monitoring equipment should have a fast response time such as an oscilloscope or an oscillograph. The following test conditions should be established.

1. Minimum and maximum relay calibrations.
2. Minimum and maximum motors.
3. Minimum and maximum line voltages.
4. Minimum and maximum loads on the compressor.
5. Minimum and maximum line impedances.
6. Minimum and maximum motor winding temperatures.

A good application is one where a clean start and acceleration to running speed is demonstrated under all the above conditions. Sometimes this is not possible and in those cases, the decision about what to do is easier to make if all the alternatives are known. A shift upward or downward in relay calibration may cure one problem, but its effect on others must be examined.

LIFE TESTING

After making the best application possible, the question still exists as to whether this combination of compressor and relay will last the required life. The first step in this process is to establish a realistic life requirement as a number of start-stop cycles. All of the major components in the system should be examined in this process. For example, it is ridiculous to specify that a relay should last for 'X' number of operations if it is known that only 'X/10' operations is the maximum life of the compressor. This is demanding and paying for quality not needed.

The best way to determine the life of a system is to test the complete system. Any simulation or substitution is a compromise and should be recognized as such. The next best test would be on a running compressor with simulated load and impedance conditions. Next to this would be a test on running motors which have the same characteristics as the compressor motors. On and off switching of the relay with inductive loads is less desirable and the same thing with resistive load is the least. A relay will behave differently on all of these tests. The dynamic weld breaking forces and contact bounce are functions of the rate of decay of coil current in the drop out range and the rate of buildup of coil current in the pickup range. (Fig. 6)

FAILURE CRITERIA

What constitutes a failure must also be defined. If the contacts do not close, the motor sees a locked rotor, run winding only, condition. Normally the overload protector would function and the relay would get another try when the protector resets. If it functions this time, probably no one would ever know, but how many trials would be allowed before a service call is necessary?

Failure to open the contacts may be the result of a run weld, a weld, or a solid weld. As to whether or not one of these is a failure depends on the ability of the system to tolerate it. If a unit has protection against running with the start winding in, then a run weld or a weld would go unnoticed. But if there is no protection the first run weld may burn out the start winding. A solid weld is always considered a failure.

A third type of failure would be drift out of calibration to the point where the system would not function. Allowable drift should be established at the time the application is made. Normally this is not a problem because ampere-turns and gravity are such major factors in the calibration and neither of them drifts. (Fig. 5)

When the test conditions and failure criteria are established, the test panels should be so instrumented, that a failure can be detected. The cycle rate is usually determined by the ability of the motor to start and stop under the test conditions. Mounting of the relay can be either remote or on the compressor but it should be recognized that this mounting could affect the number of operations before failure.

Once all the test conditions are set, several relays should be tested because life will still be a variable. When several relays have been tested, an assumption is usually made that they are random samples and adequately represent the entire population. To predict the percentage failures or survivors at a given number of operations a distribution curve is fitted to the data. Because of its flexibility we have found that a Weibull distribution has the best chance of fitting. (1) Using standard statistical procedures, percentiles and confidence limits can be calculated.

In order to make some predictions as to the expected life on motors not tested, an exponential plot is sometimes made of the characteristic life versus start winding current. This is not an exact procedure because the actual current that the contacts make and break is a function of so many test conditions and the mode of failure may change. However, there is some relationship between life and start winding current and it can be utilized to make some predictions if the consequences of an error in the prediction is not too great.

CONCLUSION

When a relay manufacturer is called upon to predict the failure rate of his product at a given value of start winding current and a given number of operations, he must qualify his answer. The test conditions and criteria of failure must be established before any meaningful predictions can be made. Once these are agreedupon however, the relay supplier should be able to furnish to the systems engineer all the data he needs to make a good reliable application.

ACKNOWLEDGEMENTS

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