

A 3-phase pump motor in some Bosch dishwashers

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Issue 1
February 27, 2026

FOREWORD

In a number of Bosch domestic dishwashers there are two pumps, each driven by a synchronous 3-phase AC motor. The 3-phase AC supply is generated by electronic circuitry in the machine. The construction and operation of these pump motors is very interesting. This article describes the construction and principles of operation of the motor in one of those pumps, based on an “autopsy” by the author of one that was replaced after 13 years of service.

Background is given on the concept of a 3-phase AC electrical circuit.

1 INTRODUCTION

1.1 The pumps

A number of families of Bosch domestic dishwashers have two pumps, both driven by synchronous 3-phase motors. They are:

- The *drain pump*. As the name suggests, this pumps water from a sump on the bottom the machine’s *tank* (the formal name for the washing “chamber”) into the sink drain, at the end of various parts of the washing cycle.
- What I call the *wash pump* (it has several names). This pumps the water from the sump into the two spray arms, in order to wash and then rinse the dishes.

1.2 The specimen

Recently, after about 13 years of service, the wash pump in our Bosch dishwasher began to misbehave and was replaced. (This misbehavior actually led to an error message that did not at all directly implicate that pump, but I was eventually able to make the connection.¹) I shortly disassembled the old pump, mainly to learn just how it had worn out (not surprisingly, it was the shaft bearings). But of course I also had to figure out just how it worked, thus this article.

¹ This story is told in detail in the companion article, “An interesting malfunction in a Bosch dishwasher”, by the same author, probably available where you got this.

2 CONSTRUCTION

2.1 The stator

In the heart of the motor is its stator—the stationary part. We see it in Figure 1.

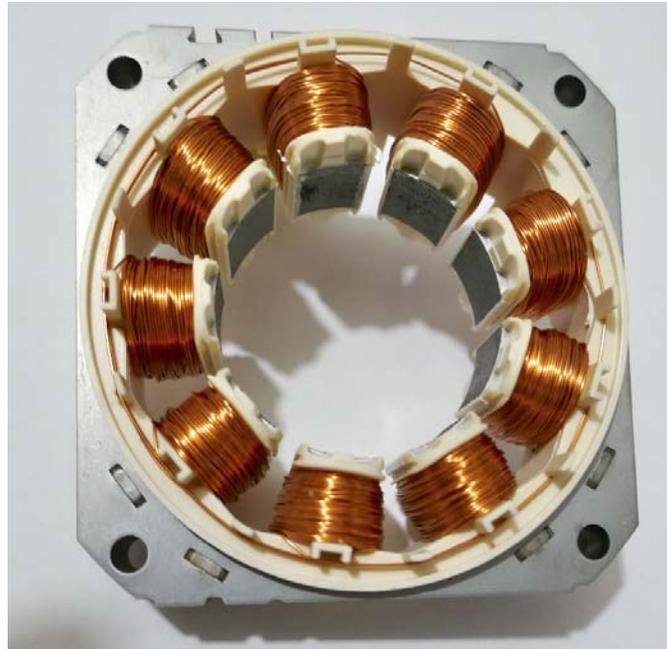


Figure 1. Bosch wash pump motor stator

The gray part is a drawn metal case over the core, a stack of thin layers (“lamina”) made of a special steel alloy.² We see that it has 9 “pole legs” that extend toward the rotor (it not present in this photo).

Around each leg there is a winding of many turns of small-gauge lacquer-insulated copper wire. These windings will be energized by a 3-phase AC electrical circuit, creating a rotating magnetic field structure that pulls the rotor around (just how we will see shortly).

We will see the rotor later after a discussion of its magnetic nature.

2.2 The motor overall

Figure 2 shows both the stator and the rotor in schematic form, very evocative of the physical form.

² Such a laminated construction is almost universal for the cores of transformers and in AC motors. Its purpose is to minimize losses from “eddy currents”, currents that would flow in the core material itself from voltages induced in that material by the varying magnetic field..

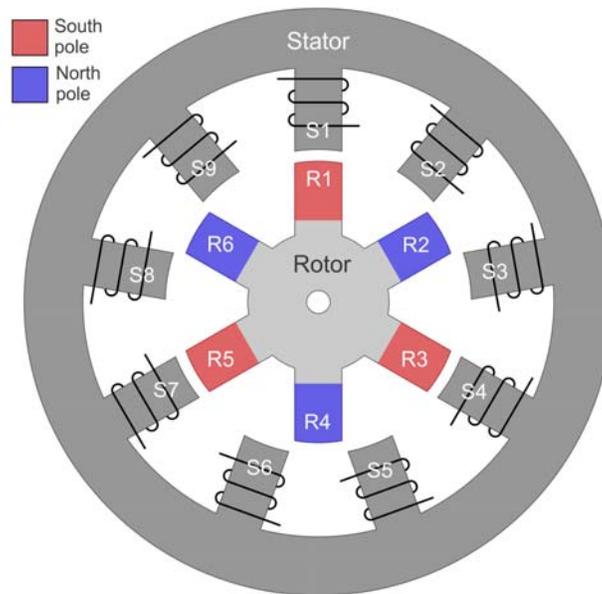


Figure 2. Motor configuration

We see in medium gray the stator core, with 9 pole legs. They are labeled S1 through S9 for reference. We see on each a schematic representation of the electrical winding on it (clearly visible in reality on Figure 1).

In the center, we see, in lighter gray, the rotor. It is made of a permanent magnet material, with six pole legs, labeled R1 through R6 for reference. It is permanently magnetized with alternating legs being of alternating magnetic polarities ("north" vs. "south"). Those polarities are indicated by the color on the illustration, the "south" legs being colored red and the "north" legs colored in blue.

2.3 The rotor

Figure 3 shows the rotor in real life.



Figure 3. Rotor

We do not see the “6-legged” permanent magnet I described; it is encapsulated in cylinder of hard plastic. The reason is that the rotor actually operates completely submerged in the water being pumped, and the plastic prevents the actual magnetic structure from corrosion (and the cylindrical form turns with less turbulence in that water).

We see, incidentally, that the near end of the shaft is worn from years of operation. The portion of the shaft that runs in the second bearing (hidden here by the motor itself) is much more severely worn.

2.4 The moniker “synchronous”

In the most common AC motors, if the magnetic field structure that propels the rotor revolves at 1800 revolutions per minute (RPM), the speed of the motor will be a bit less than 1800 RPM (how much less being dependent on the amount of torque load on the motor).

But in a *synchronous motor*, if the magnetic field structure that propels the rotor revolves at 1800 revolutions per minute (RPM), the speed of the motor is exactly 1800 RPM.

3 ABOUT A 3-PHASE AC ELECTRICAL CIRCUIT

3.1 Introduction

For the benefit of the reader who may not be familiar with this topic, which is central to the operation of this motor, here is a brief review of the concept of a 3-phase AC electrical circuit.

3.2 The basics

Electrical power in its 3-phase form is carried by a circuit comprising three “hot” conductors, in some cases accompanied by a fourth (“neutral”) conductor.

In figure 4 we see graphs of the instantaneous value of the voltage waveforms on the three “hot” conductors (labeled as phases x, y, and z), all reckoned with respect to an arbitrary reference point (we can think of it as “ground”), versus time.

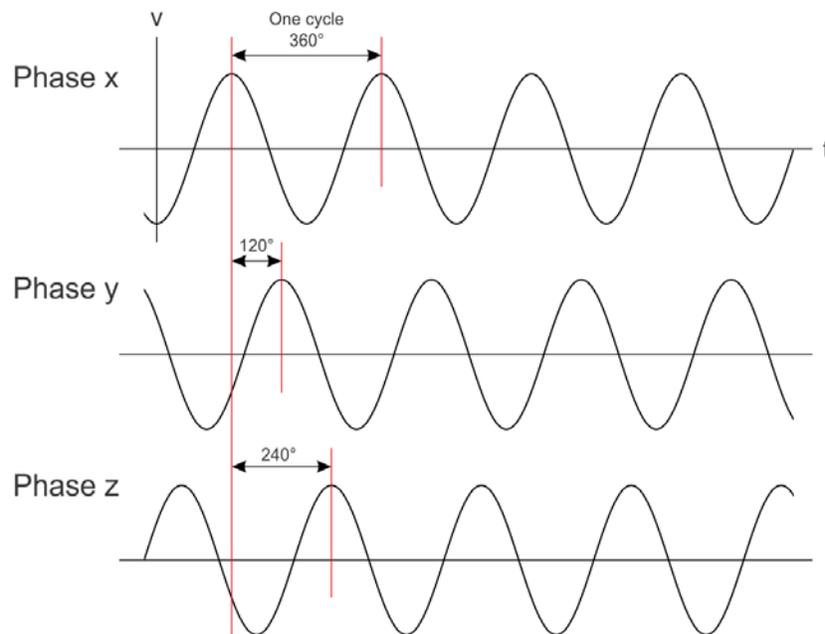


Figure 4. 3-phase electrical circuit waveforms

We see only an arbitrary period in the life of these electrical waveforms, a little over 4.5 cycles in duration.

Because these waveforms are cyclic in nature, and because they are usually described in terms of a trigonometric function, we consider the time of one cycle of the waveform as constituting 360° of an abstract “angle”. (No actual physical angle is implied.)

The first curve is the instantaneous voltage versus time on one of the three “phase conductors”, that conductor and voltage being called for reference “phase x”.

Next we see the voltage on the second conductor (“phase y”). Its waveform has the same shape as the waveform on phase x, but it occurs $1/3$ of a cycle (thus 120°) later in time.

Finally we see the voltage on the third conductor (“phase z”). Its waveform also has the same shape as the waveform on phase x, but it occurs $1/3$ of a cycle (120°) later in time than phase y, and thus $2/3$ of a cycle (240°) later than phase x.

Closing the loop, because of the cyclic nature of this matter, we see that "phase x" can in turn be thought of as being $1/3$ of a cycle (120°) later than phase z.

4 NOW, BACK TO OUR MOTOR

4.1 Winding groups

We noted that there are 9 pole legs to the stator, each with an electrical winding around it. These windings are connected in series in three groups of three windings each.

We see the arrangement on Figure 5. which I have arbitrarily laid out in a symmetrical form that is commonly used to illustrate a "load" energized by a 3-phase AC electrical circuit.

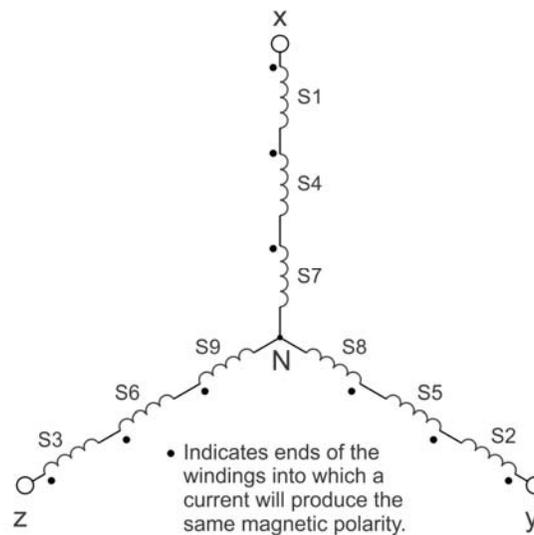


Figure 5. Winding connections

One group comprises the windings on pole legs S1, S4, and S7; one the windings on pole legs S2, S5, and S8; and one the windings on pole legs S3, S6, and S9.

The "live" end of each of these groups goes to one of the three 3-phase conductors, x, y, and z; the "other" ends of the three are tied together at the point labeled "N" (which would be conductor N if that is actually present).

This configuration of the 3-phase "loads" is spoken of as the "wye" configuration (a spelling of the pronunciation of the name of the letter "Y"); we can readily see the premise for this name (even though the "letter Y" is upside down here).

4.2 About the neutral conductor (N)

If the amplitudes of the three phase voltages (measured with respect to the N conductor) are equal (and we generally assume that), at any

instant the sum of the instantaneous voltages on the three phase conductors will be zero. (I will spare the reader the trigonometric proof of that.)

Ensuite, if the impedances of the three winding groups are equal (and I will assume they are), then at any instant the sum of the instantaneous currents through the three "legs" of the load will also be zero. This would be the current into the neutral conductor, N. Since the current in it would be zero, it serves no obvious circuit purpose, and so we actually can omit that conductor.³

4.3 Magnetic polarities and magnitudes

In Figure 6, we see a short portion of the three phase waveforms. Red lines indicate time instants to which I will refer in the subsequent discussion.

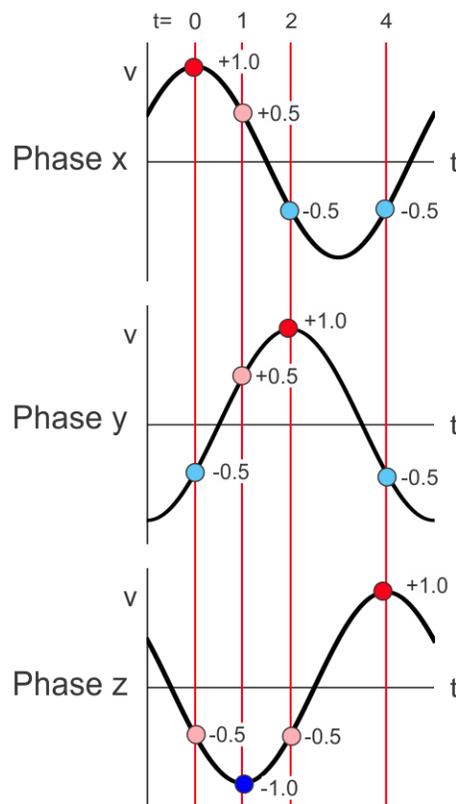


Figure 6. Winding voltages

It shows the three phase voltage waveforms, over an arbitrary period of one cycle. The red lines mark times of interest to the presentation. The time scale is in arbitrary units of 1/6 of a cycle (which fits well with the description of motor operation to follow).

³ Often in power distribution lines operating on a 3-phase basis there is provided a neutral conductor, for reasons that are outside the scope of this article.

The instantaneous relative voltage values for each phase at those instants are labeled. The colored dots show the colors I will use in some later figures to indicate those polarities and magnitudes.

The first line shows the situation at time $t=0$. Note that phase x (which energizes the windings on pole legs 1, 4, and 7) is positive (which we assume produces the north polarity on those pole legs) and at the "peak" voltage (the dark red color).

But phase y (which energizes the windings on pole legs 2, 5, and 8) and z (which energizes the windings on pole legs 3, 6, and 9) are at the moment negative (producing a south magnetic polarity), both with, in fact, exactly 0.5 of the "peak" voltage (the light blue color).

And so forth.

4.4 The movement of the rotor

4.5 Introduction

The figures to follow show the situation at successive instants. They show the effect of the voltages on the stator pole legs in terms of magnetic polarity and magnitude. This in turn leads to the rotor being in equilibrium at a certain position at that instant.

The pole legs of the stator are labeled S1 through S9. The pole legs of the rotor are labeled R1 through R6. There is also a black arrow on rotor pole leg R1 to help us keep track of the position of the rotor.

We recognize that, simplistically, magnetic "pole tips" of opposite magnetic polarity ("north" vs. "south") will be attracted to each other, and conversely, pole tips of the same polarity will be mutually repelled.

So, for ease in following the action intuitively, on the stator I have made the pole legs that are north at the moment red and the ones that are south at the moment blue, while for the rotor I have made the pole legs that are north blue, and those that are south red. **The result is that stator and rotor pole legs marked in like colors attract; those marked in "opposite" colors repel.**

On the stator, I have colored the pole tips exhibiting at the moment a "peak" magnetic field deep red or blue, while those exhibiting a lesser magnetic field are colored in a lighter red or blue.

Again, the time scale is in arbitrary units of 1/6 of a cycle. The unit of position is half the angular spacing between stator pole legs. A full revolution is 18 position steps.

4.6 At $t=0$

In Figure 7, we see the situation at time $t=0$, when the rotor is in position 0.

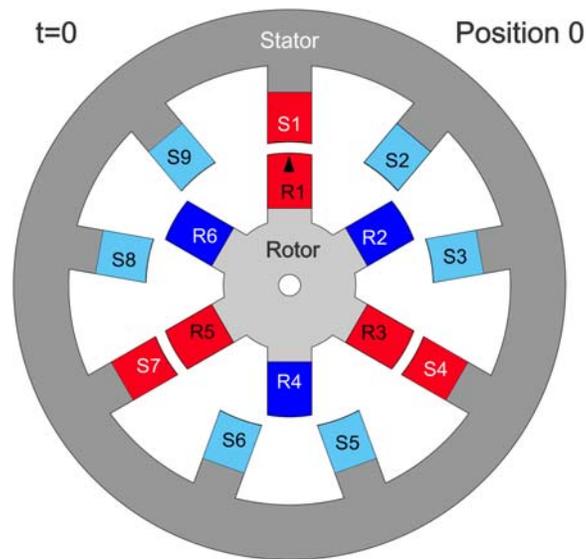


Figure 7. Rotor position 0

Stator pole leg S1 is “full north”, and so it attracts rotor pole leg R1 (which is permanently “south”).

Stator pole legs S2 and S3 (each of which is “south” at half the “full” strength) jointly present a south polarity, seemingly from a wide “pole” centered between them. This attracts rotor pole leg R2 (which is permanently “north”). toward that place.

This story repeats two more times around the motor.

The result is that, at this instant, the rotor is in equilibrium at the position shown.

4.7 At $t = 1$

In Figure 8, we see the situation at time $t = 1$, when the rotor is in position 1. This is $1/6$ cycle later in the electrical waveforms than for the prior case.

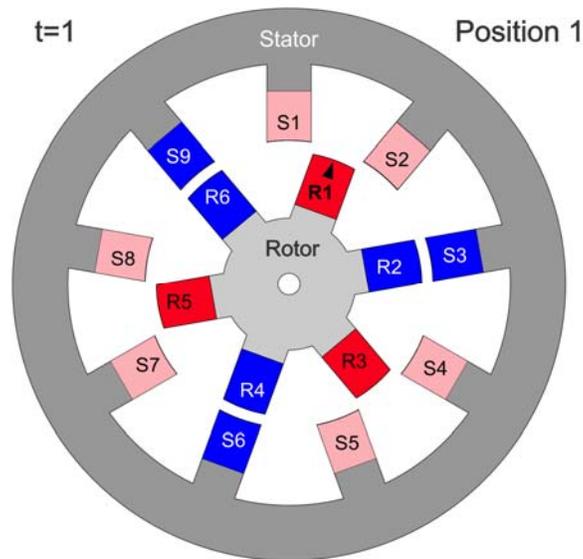


Figure 8. Rotor position 1

Now, stator pole legs S1 and each exhibit the “south” magnetic polarity, each at half of the “full” value. So together they seem to the rotor to be a wide pole tip centered halfway between S1 and S2. Again this attracts rotor pole leg R1 to that location.

Stator pole leg S3 exhibits the south magnetic polarity, at “full” strength. It attracts rotor pole leg R2 to it.

Again, this story repeats two more times around the motor.

The result is that at this instant, the rotor is in equilibrium at the position shown.⁴

Note that in reality the change from the situation of Figure 7 to that of Figure 8 is continuous as the electrical waveforms progress; the rotor does not “jump” from position 0 to position 1.

⁴ In reality, if there is any torque “load” on then motor shaft, the rotor will be a little bit “earlier” in position than shown here, but that “lag” does not accumulate with time, so the motor speed is indeed identical to the speed at which the magnetic field structure rotates.

4.8 At $t=2$

In Figure 9 we see we see the situation at time $t=2$, when the rotor is in position 2. This is $1/6$ cycle later in the electrical waveforms than in the prior case. The details of the story are comparable to those before.

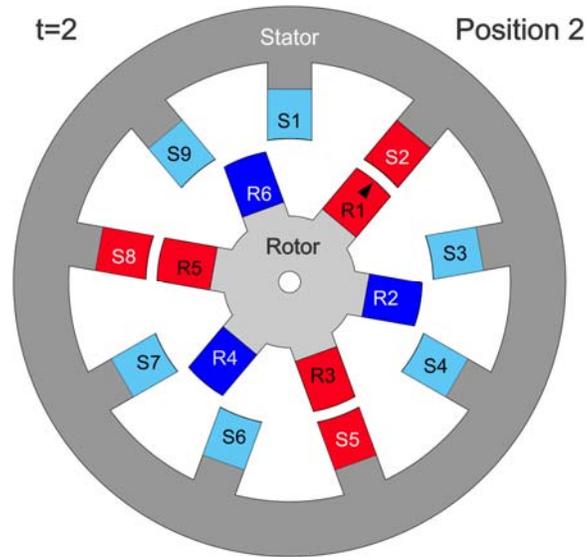


Figure 9. Rotor position 2

4.9 At $t=3$

In Figure 10 we see we see the situation at time $t=3$, when the rotor is in position 3. This is $1/6$ cycle later in the electrical waveforms than in the prior case. The details of the story are comparable to those before.

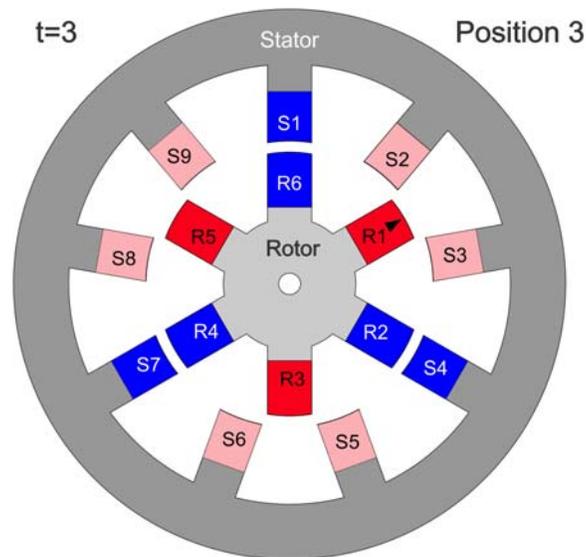


Figure 10. Rotor position 3

4.10 At $t = 4$

Finally, in Figure 9 we see we see the situation at time $t = 4$, when the rotor is in position 4. This is again $1/6$ cycle later in the electrical waveforms than in the prior case. The details of the story are comparable to those before.

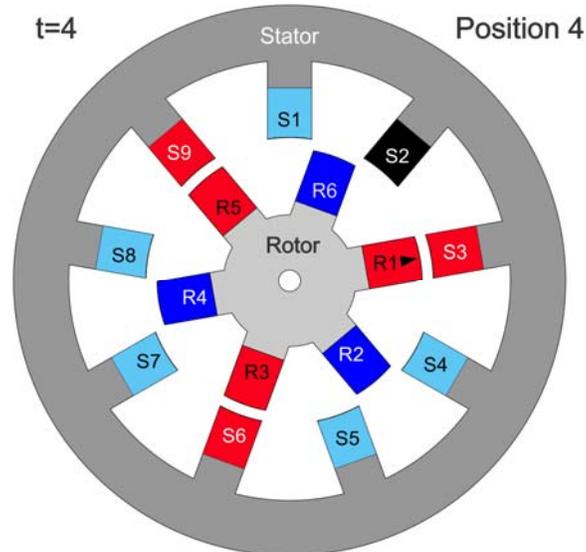


Figure 11. Rotor position 4

4.11 A whole revolution

At 3 cycles after $t = 0$, the rotor will have moved through 18 positions, one whole revolution, and will be again as seen in Figure 7.

Thus, if the frequency of the 3-phase AC signal is f_{AC} , the rotor will turn $f_{AC}/3$ revolutions per second, or $20f_{AC}$ revolutions per minute (RPM).

5 THE ACTUAL AC FREQUENCY?

I do not know at what frequency is the AC signal used for this pump motor in actual operation—that might even vary over different parts of the washing “cycle”, or between different “cycles”.

The motor nameplate suggests an operating frequency of 150 Hz. That would result in an motor/pump operating speed of 3000 RPM.