The Compressor Breaks:

Did you know..... Compressor failures can be grouped into 4 categories:

The reason for failure determines the “next step” in diagnosis.

1. Locked rotor.
2. Runs - won’t pump.
3. Electrical: short or grounded windings.
The Compressor Breaks:

Did you know….. Compressor failures can be grouped into 4 categories:

Worth repeating: The reason for a compressor failure will determine the “next step” in diagnosis.

Before we dive into both mechanical and electrical analysis, we need to get “Back to Basics” with regard to electrical principles as they apply to HVAC hermetic compressors. After all, “Fundamentals bring clarity to complex situations.”
Basic motor theory:

What causes an AC motor to rotate?

The magnetic field lines around a long wire which carries an electric current form concentric circles around the wire.

Direction of the magnetic field is perpendicular to the wire and is in the direction the fingers of your right hand would curl if you wrapped them around the wire with your thumb in the direction of the current.
Basic motor theory:

What causes an AC motor to rotate?

The stator current, labeled here as “Is” induces a magnetic field into the “rotor” of the motor.

The rotor has individual bars which run somewhat parallel to the shaft, hence giving the appearance of a “squirrel cage” rotor.
Basic motor theory:

What causes an AC motor to rotate?

There is a magnetic field induced into each “bar” of the rotor.

The rotor bar fields are the key function which creates motor rotation…

That is, opposite charges within the stator & rotor attract and like charges repel, thus inducing rotor rotation.

Note bars within the rotor
Basic motor theory:

What causes an AC motor to rotate?

If you freeze the moment it time power is applied to the motor, the rotor does not have any motion. Therefore, the only resistance opposing current flow is the stator winding resistance.

We quantify this zero rotor RPM current as “LRA” or locked rotor amperage.
Basic motor theory:

What causes an AC motor to rotate?

Poles- An AC induction motor will have a given number of “poles” per stator phase, which determine the motor RPM.

We can calculate a motor RPM by:

\[(120 \times f) \div \# \text{ of poles}\]

Ex: \[(120 \times 60) \div 4 = 1800 \text{ RPM synchronous.}\]

AC induction motors cannot run at a synchronous RPM!

Any thoughts as to WHY?

<table>
<thead>
<tr>
<th>Poles</th>
<th>RPM at 50 Hz</th>
<th>RPM at 60 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3000</td>
<td>3600</td>
</tr>
<tr>
<td>4</td>
<td>1500</td>
<td>1800</td>
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<td>12</td>
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<td>450</td>
</tr>
<tr>
<td>18</td>
<td>333.3</td>
<td>400</td>
</tr>
<tr>
<td>20</td>
<td>300</td>
<td>360</td>
</tr>
</tbody>
</table>
Basic motor theory:

What about “phase”?

“Phase” relates to a full 360° cycle or period as a reference.

Residential applications are “single phase” with the symbol 1Ø.

All residences in the USA operate at 60 HZ, or 60 cycles per second.
Compressor Motor theory:

Single phase compressor motors are available in a variety of configurations. We will look at:

- **PSC** - Permanent Split Capacitor
- **CSCR** - Capacitor start, capacitor run
PSC motor theory:

PSC- Permanent Split Capacitor- As the name implies, the capacitor is permanently in the compressor motor circuit. The run cap is in series with the start winding; parallel with the run winding. Note the same configuration for the OD fan motor.

Pro: minimal moving parts. Con: Starting torque is limited.
**Permanent Split Capacitor** - PSC.

**Q.** What does the run capacitor do?

**A.** In an inductive circuit, as in a hermetic compressor motor, the voltage and current are out of phase, with \( E \) leading \( I \). The greater the shift, the less efficient the motor and electrical energy is given up as heat instead of “converting” to magnetism.
Permanent Split Capacitor - PSC.

Here you see the voltage and current closer in phase; PF increased.

A 100% efficient motor would have a PF of 1.0. As this is not possible, we can get close! **Q.-** What if you have a failed 60uF, 440 VAC run cap, and all you have in your truck is a 15uF and 45uF, both @ 440 VAC. How would you make this repair???

**Answer -** Wire the capacitors in parallel for a total of 60uF.
Permanent Split Capacitor - PSC.

Although a run capacitor does in fact add torque to the motor, it’s primary purpose is to correct the “power factor” as much as possible by reducing the phase shift. Bringing (E) and (I) closer in phase, the power factor improves and current goes down.

uF rating - MUST BE replaced with the same microfarad rating, uF.

Voltage - You can go higher in voltage, but not lower, as the run cap “sees” counter EMF.
**CSCR motor theory:**

CSCR- Capacitor start, capacitor run- Basically a PSC with an added capacitor.

The start cap, “CS” is in parallel with the run capacitor, yet is only in the circuit momentarily. This staggers the S and R currents to provide an ideal 90° phase shift. Like “1st gear” in a transmission, this provides maximum starting torque.
**CSCR motor theory:**

CSCR- Capacitor start, capacitor run-  Basically a PSC with an added capacitor.

As with your truck, you don’t want to remain in 1st gear when you come up to speed. The start relay “CSR” operates on a voltage potential (hence the “potential relay” to disengage the CS from the circuit.

Note that the CRS contacts are NC, which means “normally closed.”
PSC motor theory:

CSCR- As the compressor RPM increases, so does its “counter EMF.” The CSR relay coil is energized by the counter EMF it “sees” at terminals 2 and 5. See if you can locate where the voltage potential comes from between terminals 2 and 5!

The CSR coil has a “pick up” voltage rating, at which point it energizes and opens the NC relay contacts between terminals 1 and 2, thus removing the CS from the circuit.
PSC motor troubleshooting:

1. If the CSR relay contacts “stick closed” what will happen?
2. If the CSR relay contacts are permanently open, what will happen?
3. If the CS start capacitor fails, what will happen?
Burn baby, burn!
PSC motor troubleshooting:

Compressor winding troubleshooting discussion:

1. How do you test the resistance of the compressor windings?
2. What should the winding resistance be?
If open winding is suspected, check at the terminals. The wiring might be incorrect, or a wire burnt off.
Scroll compressors have molded plugs, but can still be mis-wired.
Basic motor theory:

What about “Single Phase”?

The name says it all: there is one power phase.

One “revolution” = 1/160 of a second @ 360°.
Basic motor theory:

What about “3 phase”?

“3 Phase” relates as the name implies: 3 power phases, with motors having 3 stator phases.

Staggered 120° apart, 3 phase motors are inherently “more efficient” with reduced motor losses.

Commercial applications frequently utilize 3 phase with the symbol 3Ø.

3Ø motors are typically 208/230, 460/575 VAC.
Basic motor theory:

Typical schematic representation of a 3 phase compressor. Note the (3) power phases, lines 21, 23 and 25, however (2) of the (3) are interrupted by means of the compressor contactor “CCI.”

Crankcase heater, “CCH1” provides a complete path for current flow when CC1 is deenergized. When CC1 energizes, power is shunt across the heater and it is electrically removed from the circuit.
The Compressor Breaks:

We’re going to look at the two types of hermetic compressors commonly used:

*Reciprocating*- Linear motion; reed style valves with a valve plate.

*Scroll*- Helical, elliptical pattern with a “fixed” and orbiting scroll. No valves! ..at least internal to the compressor.
The Compressor Breaks:
We’re going to look at the two types of hermetic compressors commonly used:

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The Compressor Breaks:

We’re going to look at the two types of hermetic compressors commonly used:

**Scroll**- Helical, elliptical pattern with a “fixed” and orbiting scroll. No valves! ..at least internal to the compressor.
The Compressor Breaks: Symptom: Rotor lock

“Big 3” symptoms: compressor with a locked rotor:

- Compressor rotor will not turn.
- Compressor pulls locked rotor amperage, LRA.
- Compressor cycles off on internal overload, IOL.
The Compressor Breaks: Symptom: Locked Rotor

If the rotor will not turn, there are “likely” reasons and “not so likely” reasons.

- Obtain the operating data to isolate the “likely” from “not so likely” to repeat failure.
  - Before replacement, if possible.
  - AFTER replacement: Start up data!
- Q.- Why do compressors hum?
Locked Rotor- Refrigerant floodback
Possible cause: Poor airflow!

Systems require 350-450 CFM/ton

Don’t assume: Measure it! (ESP)

- Check against the unit fan performance table:
  - Blower speed set correctly?
  - Check speed tap or reset DIP switches
  - **High duct static** - See “Service Facts” for unit ESP capability:
    - Ductwork too small
    - Too few outlets- supply and / or return
    - Crushed ducts, dirty filters, dirty evap., etc.
Locked Rotor - Refrigerant in the compressor crankcase

Possible causes:

System overcharge

- High Subcooling
- Low Superheat
- Discharge and suction pressures beyond manufacturer’s charging table.
  
  □ Q.- Where can you find charging data?

Flow control not operating properly

- Low / no superheat
  
  □ Refrigerant flooding the evaporator
  □ “Boils” oil in bearings
  □ Foams oil in crankcase
Locked Rotor - Refrigerant in the compressor crankcase
Possible causes:

Leaking check valve: refrigerant bypassing flow control
- Refrigerant flooding the evaporator
- LOW system superheat!

*If the check valve is bypassing refrigerant, liquid refrigerant can dump directly into the evaporator coil, once there, it cannot evaporate fast enough to keep liquid from entering the compressor.
Locked Rotor - Refrigerant floodback
Possible causes:

- **Evaporator fan failure:**
  - Run capacitor
  - Motor cycles on IOL
  - Open or shorted windings
  - Motor bearings

- **Application**
  - Incorrect rotation
  - Incorrect blower wheel
How do you test a run capacitor under a load?

Measure voltage at the common and hermetic terminals of the capacitor.

Measure amperage of the start winding

\[
\text{Measured Amps} \times 2650 \quad \text{Measured Voltage} \quad = \quad \text{Actual Capacitance}
\]
Liquid in the crankcase = **Boil the Oil**
Boil the Oil

This is a 2 cylinder compressor, this shows the normal oil level. As you can see, the oil covers the lower bearing. The oil pickup is at the very bottom of the crankshaft. Since oil will float on top of liquid refrigerant, once the oil level is above the oil pickup, the only oiling is what oil is entrained in the refrigerant.
Boil the Oil

This is a 2 cylinder compressor, this shows the normal oil level. As you can see, the oil covers the lower bearing. The oil pick up is at the very bottom of the crankshaft. Since oil will float on top of liquid refrigerant, once the oil level is above the oil pick up, the only oiling is what oil is entrained in the refrigerant.
Boil the Oil

7 pounds total additional charge reaches center of upper cylinder

Normal Oil Level
Boil the Oil

Normal Oil Level

11.5 pounds totally fills upper cylinder
Flood Marks- Visible indication from factory tear down which reveals liquid which was present in the crankcase.
Flood marks
Sometime hydraulic action even closes up the discharge line. This is rare, but when it happens, the internal pressure relief will open immediately.
The Compressor Breaks:

Symptom: **Runs: Won’t pump**

Possible cause:

- Internal discharge line on compressor is ruptured.
  - Hot gas from discharge valves is directed right back to the suction valves.
    - Discharge temperature at compressor is warm, not **HOT** as it should be.
    - IOL will trip fairly quickly
A compressor is a very good vapor pump, but when it tries to pump liquid, bad things happen. This is what happens to the internal mufflers when a compressor tries to pump liquid and it actually starts. Some noise complaints can be tied to this as well, since a swollen muffler will decrease the clearance between the shell and the muffler.
Hot gas leaking through reversing valve
The Compressor Breaks: 
Symptom: *Runs*: Won’t pump

- Compressor valves are compromised.
  - Suction valve(s) broken; compressor cannot pump. Symptoms are:
    - Discharge temperature very low.
    - High side low, low side high.
    - Low amperage
    - Could / will take a very long time to trip IOL
Broken suction valve *(This is the result!)*

Trash in discharge valve *(This comes first)*
This valve is worn out. Beach sand was found in the crankcase.
There USED TO BE a connecting rod journal here!
The Compressor Breaks: Symptom: Runs: Won’t pump

- Another diagnosis of “Runs - won’t pump…” is the internal pressure relief opening.
- The IPR will open at an approximate 450 PSI pressure *differential*.
- “Spewing” noise while compressor is running. This is discharge gas that will heat up the internal overload to shut down the compressor. Not good.
IPR valve- Trane reciprocating compressor
The Compressor Breaks: Symptom: Electrical

- Electrical problems are usually:
  - **Starts**- but trips breaker shortly after.
  - **Trips breaker immediately**: never starts.
  - **Contactor pulls in**- nothing happens.
  - **Miswiring**-
    - Just like “Rice Krispies”
      - Snap, crackle, pop
    - Remember… It doesn’t know the words…. So it hums.
The Compressor Breaks:
Symptom: Electrical- Starts, but trips the breaker

- Needs start assist, a.k.a.- “Hard Start Kit”
  - As discussed, this staggers start and run winding current 90° for maximum torque.
  - Reduces amount of time compressor pulls locked rotor amperage.
  - Compressors which are worn; PSC does not have sufficient torque.
  - Recip without a hard start kit- when matched with TXV-NB. (Oops)
Voltage: How low can you go?

Remember the “10% Rule”?

Does Outdoor Air Temperature affect the voltage rating?

NOTE A: START KIT REQUIRED. IN THIS AREA RANDOM OVERLOAD TRIPS MAY OCCUR WITHOUT MAJOR IMPACT ON COMFORT AND NO IMPACT ON TRANE WARRANTY.
The Compressor Breaks:

Symptom: Electrical: Starts, but trips the breaker

- Hard start kit (factory or field installed) not functioning- OR- not the right one!
  - Start relay or start capacitor malfunction
    - Start relay coil burned out / points shorted
    - Start relay coil not picking up (relay position)
  - Start capacitor blown
    - Start capacitors are typically rated for 1 second “on” and 59 seconds “off”. Maximum on time is 4 seconds.
    - Extended “on” times shorten capacitor life.
Potential relay is position sensitive! Look for the “tab”

"Tab right" example

Note: orientation does change PU and DO voltage ratings!
The Compressor Breaks:  
**Symptom: Electrical- Starts, but trips the breaker**

- Runs, but pulls high amperage- greater than FLA
  - Compressor worn- Replace: measure oil from old pump.
  - Run cap MFD is incorrect. Verify with cap tester.
  - Contactor voltage drop: Measure across **LINE** and **LOAD** terminals of contactor points.
  - Wire gauge too small! - Greater than 10 VAC *difference* at unit when compressor is OFF compared to ON
  - Loose connections at disconnect or contactor
The Compressor Breaks:
Symptom: **Electrical**- Immediately trips breaker

- Resistance measurements- Use an ohm meter reading to check for:
  - Terminal(s) grounded
    - Less than 50K (50,000) ohms to ground.
  - Turn to turn shorts
    - C to S and C to R open readings indicate an open internal overload, IOL.
    - **Normal**- Ohm reading from C to S plus C to R will be very close to S to R ohm reading.
Do the math!

S to C = 2.6 ohms
R to C = .60 ohms
S to R = ??
What is the problem?

S to C = infinite ohms
R to C = infinite ohms
S to R = 3.2 ohms
Do the math!

T1 to T2 = 0.6 ohms
T1 to T3 = 0.60 ohms
T3 to T2 should = ??
The Compressor Breaks:
Symptom: *Electrical- Immediately trips breaker*

Mega ohm Readings

- There are accurate ways to read “leakage.”
- Resistive leakage to ground can vary upon winding surface area. i.e. wire diameter, number of turns, stack height and winding temperature...
Megaohm values

- Dangerous.......................... 2 megohms & lower
- Poor...................................... Less than 50 megohms
- Questionable.......................... 50 to 100 megohms
- Fair........................................ 100 to 500 megohms
- Good...................................... 500 to 1000 megohms
- Excellent................................. 1000 meg to infinity

- Scrolls can be misleading IF there’s fluid in the crankcase.
What limits current flow if you have:

a) ...a short to ground

b) ...a locked rotor
IOL is NOT an operating control!

This shows a burned out start winding. Likely because the start relay did not drop out.
Burnout - Usually accompanied by black, acidic oil. Not good.
Green oil vs. green slime

- When a system operates for an extended period of time, while open to the atmosphere or when contaminated with moisture, *nasty things* happen inside the unit.
- Moisture + oxygen + heat + oil + copper tubing = *Green oil*
- All of the above + *time* = *Green Slime*
Green Oil

- Green oil has a green color. The green tint is due to the presence of copper ions in the oil that are released by excessive moisture and oxygen in the system. This can vary from a light green tint to deep green.

- One unique thing about green oil is its viscosity; it is the same as the original oil.

- Even though it is green, has a pungent odor and can be mildly acidic, it can be cleaned from a system.
Filter Driers

Liquid and suction- When do you need them?

- **Liquid drier**- EVERY TIME THE SYSTEM IS OPENED TO THE ATMOSPHERE, PERIOD. Any questions?
  - R-410a uses POE oil: *Very hygroscopic*!
  - Only a DRIER will remove moisture from POE oil: vacuum will not!
  - After a burn out, as the LL drier will absorb acid.
    - MUST REPLACE THE LL DRIER after the replacement compressor has been operating approximately 72 hours, or by OEM requirements. (Common sense prevails too!)
  - LL drier will filter / catch debris / particulate.
- Driers are not sized by line diameter alone!
  - Example- C-163 nomenclature:
    - 16 = 16 cubic inches of desiccant
      - 3 = connection OD (# of 8ths) as in 3/8”
Filter Driers

Liquid and suction- When do you need them?

- **Suction drier**- After a burn out, or even upon an initial installation. Why?
  - Possible line contamination in a retrofit installation.
    - Think about it- where does any debris in the suction line go upon start of the replacement system?
  - “HH” style driers will assist in system clean up

- Suction driers after a burnout should be removed when clean up is complete:
  - Verify by acid testing
  - Verify suction line pressure drop:
    - R-410a- 5 # maximum PD
    - R-22- 3 # maximum PD
Green Slime Summary

- *Green slime* is, in fact, green oil that is left in a system that has operated with an unrepaired leak, out of or low on refrigerant, in which large amounts of moisture has entered.
- It is created by a combination of moisture, heat, oxygen, oil, and TIME.
- *It attaches to tubing walls and is nearly impossible to clean up.*
- It is very acidic and will continue to eat away at copper and aluminum throughout the system.
Black Oil

The discussion on green oil and green slime won’t be complete until we talk about Black Oil.

Black oil caused by a compressor burnout is highly acidic.

Compressors have been opened in the lab months after compressor removal from the system ….and green smoke emits from the oil!!
This is your compressor on drugs
Black Oil

- If the compressor *died a quick death*, all of the contaminants remain in the old compressor. This system can be saved.

- If the compressor continues to try to run, black sludge is sent throughout the system. Think about the effect on the TXV?

- Inspect the liquid line driers AND TXV- If *black sludge* is through them, there will be a lot of labor to put the system back in service.
Samples:
1. Highly acidic POE
2. Acidic mineral oil with presence of green slime!
3. Virgin MO
Low System Charge:

- There is a bad habit that needs to be broken. It’s known as “Topping-off”.
- The EPA does allow systems with less than 50 pounds of charge to be recharged without leak repair, so topping off is not illegal, technically.
- However, this IS hard on equipment! Although worst case, here are some examples.
Heat due to lack of lubrication welded the journal to the crankshaft!
Low Oil Truth…. And consequences!

- Low oil can be a compressor killer.
- Every compressor will pump small amount of oil when it is running.
- When that compressor runs out of refrigerant to pump, it wants to pump something.
- Until the refrigerant flow rate returns to normal, the oil will never return.

Never add oil to a system until the Refrigerant charge has Been verified!!!
Badly scored bearing

Trash in Bearings
= a badly scored crankshaft

Trash in Bearings
Vacuum

- Never start or run a compressor in a vacuum.
- The refrigerant vapor acts as an “insulator”.
- *Without this barrier*, electricity can and will bounce around inside the shell.
- The energy created can arc to ground, and can take out the compressor terminals.
WHO ever said, “2 out of 3 aint’ bad!”
Handling damage

- Compressor are pretty tough. They are designed to withstand an 18” inch drop. (However, I’d recommend not performing the test yourself!)
- They are not designed to be tumbled, rolled, thrown off trucks, or buildings.
- Condensing units must ride in your truck or van RIGHT SIDE UP!
- Next slide is one that “took a ride”.
Normal......
Abnormal...Not meant to be dropped off of a truck.
Mounting Springs

- Mounting springs can be either distorted or broken.
- A distorted spring can be nested, where the turns are collapsed into one another.
- Or…. actually bent out of shape.
- This is normally caused by shipping or rough handling.
Mounting Springs

- Or… a spring or springs may be broken.
- This can be caused by compressor “bounce” while trying to pump liquid, or rapid off-on due to contactor “chatter.”
- The net result is a metallic clicking noise while running, could also be a click or thump on start up or shutdown.
- This comes from the compressor frame coming in contact with the inside of the compressor shell.