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Practical Forensic Engineering -- Property -- Part 2©

APPLIANCE WATER LOSSES

DISHWASHERS AND WASHING MACHINES

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Course Description:

This course is a follow-on to Practical Forensic Engineering – Property – Part 1. In this course we delve into one of the more common issues regarding Property Losses – water losses from appliances. The course covers some general issues and then focuses on two major household kitchen appliances – washing machines and dishwashers. These machines cause the greatest number of appliance water losses. The course discusses the losses and causes most often encountered, illustrates the failure conditions with photos of actual losses, and provides practical advice and guidance in determining the origin, cause and timeframe of the event.

INTRODUCTION

Appliance water losses are a very significant issue for insurers. Travelers Insurance reports that plumbing and appliance losses represent 19% of property claims, more than from weather. Individual claim losses can be very large, often exceeding $50,000 and increasing if the loss is on the upper story of a multi-story structure. Water goes where it wants to and even a small leak can be extremely costly to investigate, remediate and repair. Often a home becomes unlivable due to a water loss event and temporary housing is then an additional cost factor.

Identifying the precise cause of the loss is usually fairly straightforward, however there are a number of instances where the loss simply cannot be recreated in testing. For our convenience, these are termed one-time only events. Interestingly, even if the cause of the loss is identified and the responsible component replaced, most homeowners will be uncomfortable retaining the machine after it damaged their house.

In this course we will deal only with common major household appliances that retain or process water. Each of these machines has a pressure boundary which must be maintained in order to avoid water leakage. The machine does not have to be in operation for it to leak, but the pressure boundary must be compromised. It is not at all unusual for the homeowner to arrive home after a week of vacation to find water running out the front door. These instances in particular can cause huge amounts of damage due to the length of time the water is running and the potentially large volume of water that escaped. There is a lot to be said for knowing where the whole-house shutoff valve is located and closing it before one leaves for an extended period. If one has a well, shut off the breakers for the well pump and open a faucet. If you have city or county water, expect a large bill to cover the lost water.

Upon investigation, many appliance leaks are not from the appliance, but are from the water supply to the machine or from the drain system, both of which reside outside of the machine. Often these are installation issues rather than manufacturing defects. Common installation issues are poorly made hose or tube connections and kinked or cut tube material and are almost always found to be contrary to the manufacturer instructions. Failure to follow the manufacturer instructions is an installation defect that places potential liability on the installer.

THE ROLE OF THE FORENSIC ENGINEER

Why do we need a forensic engineer? After all, appliance service technicians have the training necessary to diagnose and repair a failed appliance, why can't they determine the cause?

PE Registration

The Licensed Professional Engineer has a distinct advantage over the trained and certified appliance repair technician in a number of ways, the first of which is that he is licensed as a professional for practice in the state in which the loss has occurred. This provides a certain amount of credibility that distinguishes him from the technician. His formal, sealed report provides the insurance client with a credible basis for decision making both as to policy coverage and as to subrogation.

Experience

The appliance technician may have years of experience in diagnosing and repairing appliances, and he has an advantage here. But, with a little research and preparation, one can diagnose most common water loss failures with relative ease. Experience in doing so and the application of the Scientific Method to solving the problem will get one to the right place. The internet is full of information to assist with particular appliances or models of appliances, and you can also find data on previous failures if there have been repetitive issues with a particular machine or part.

Determining the Extent of Property Damage and the Cause of Property Damage

The technician does not get involved with determining the cause or extent of the damage resulting from the loss. The insurance client wants the forensic engineer to identify if the particular damage was the result of the instant loss or not. If not, they want you to identify the actual source or sources of the damage. It is fairly common to uncover preexisting damage after a water loss, and the technician will not be concerned with the extent of damage or its causes. Sorting out immediate damage from pre-existing damage and determining the respective causes is one of the roles of the forensic engineer. There is also the potential issue of mold damage, particularly for pre-existing damage, due to long-term hidden leakage, or due to failure to immediately dry out the affected areas. Mold inside wall cavities is not an abnormal surprise.

Determining the Repair Protocols

The insurance client will normally want you to identify or recommend a proper repair scope. This will include determining if structural components are deteriorated or damaged to the point of repair or replacement (if they are in that condition after a very recent short-term water loss, the damage is not likely from that loss). The client may also want you to recommend methods of drying out the affected areas and treatment of mold that may have resulted. In most cases, the restoration contractor will handle these issues, but if not, unless you have appropriate training, you should recommend an independent industrial hygienist (not a mold remediation contractor) to inspect and develop mold remediation protocols for significant mold issues. For losses where there is structural damage, identification of the applicable building code should be part of the repair protocol. With the advent of the International Existing Building Code, the repair process generally allows like-for-like material replacements and inspection authorities are limited in imposing code upgrades. Many engineers remain under the impression that such repairs must meet the current International Building Code or International Residential Building Code as adopted by the state.

Taking Custody of Evidence

If a service technician replaces a part, chances are that it will end up in a dumpster, preventing recovery to support subrogation. If the investigation and testing lead to identification of a subrogation opportunity, then the faulty machine or faulty part must be taken into evidence by the forensic engineer on behalf of the insurer. If service to the machine occurs prior to the investigation, the adjuster or restoration contractor should advise the homeowner to retain any replaced parts.

For testing, most often it will be best to take the machine into evidence for shop testing, as there is likely a better setup in the shop than in the field. However, field or site testing is possible and often appropriate. In most cases, the restoration contractor has already been on site and has initiated the dry-out process when the forensic engineer arrives. Chances are the contractor has also moved the offending appliance out of its installed position and placed it in a garage or outside. In this case, take photos of the machine in the "as-found" condition, and do a visual examination of the machine. If water and power are available, functional testing can be done on site with a garden hose and an assortment of fittings and supply hoses. I choose on-site testing if I see staining, corrosion, or other evidence of an inlet valve failure but otherwise prefer to take the machine into evidence and to the shop. Failed inlet valves can be separated from the machine without destructive means and one may not need to take the entire machine. Ultimately, the manufacturer will likely request that the offending part be shipped to them for testing (without shipping the entire machine if possible) and the machine can be left on-site for repair and continued service.

When taking evidence, be certain to photograph the material on-site, create a Chain of Custody, label and package the evidence and follow proper evidence collection, storage and disposal protocols. The forensic engineer becomes the custodian of the evidence and is responsible for it.

COMMONALITIES

There are certain commonalities between appliances and between their installations. The latter are primarily related to the water supply and drain systems that are outside of and not directly a part of the machines themselves. The more important ones are discussed below.

Pressure Reducing Valves

Many homes today have pressure-reducing valves installed, partly as a result of code changes over the past 15 years requiring these devices on domestic water supply systems. These adjustable valves reduce the street water pressure, which may achieve pressures in excess of 135-psi, down to 55-psi to 60-psi, the normal domestic household water pressure. The pressure reducing valve protects the domestic water supply from street overpressure and some surge events. They also prevent backflow. System (street) pressures rise overnight when water usage is minimal. The city or county system has to maintain enough system pressure to yield a reasonable pressure to the furthest house from the pumping station, which means that houses closer will have a higher street pressure. The pressure reducing valve is there to prevent a water loss may result from excess supply pressures. Examples of such a loss may be undercounter canister filters that are often rated at 100-psi. Older homes may not have a pressure reducing valve installed, and houses on well water will not have one installed because the pressure is regulated at the well tank.

Photo # 1 -- A typical domestic pressure reducing valve. Generally, it can be identified by its shape and will be located just after the whole house shutoff valve. Not all homes have them, and they do require regular testing as they are subject to wear. This valve protects the domestic water system from overpressure.

The pressure reducing valve is a diaphragm valve and operates continually as street pressures change. They do wear out. Replacement kits for internal parts are available, but most often the entire valve is replaced if it fails. Attachment B contains a page from a Zurn brochure and describes how the valve works. The entire brochure is available at **www.zurn.com**.

These valves can fail due to debris accumulation. The valve in the following photo was taken into evidence in case it had failed but for various reasons was not tested:

Photo #2 – Debris and corrosion can disrupt performance of a pressure reducing valve. This particular one was not functionally tested.

For testing, or as good practice, if you suspect that the pressure reducing valve has failed, place a water pressure gauge (available at a home store with a hose fitting on it for about $10) on an external hose bib of the house. If it reads more than 60-psi, a pressure reducing valve is either not present or not operating properly. You can leave the gauge in place overnight to obtain the overnight pressure as well if a gauge with a maximum pressure hand is used. As a reference point, the typical pressure-temperature relief valve on a water heater will discharge at 150-psi.

Photo # 3 -- This is an inexpensive pressure gauge used to check the proper function of a pressure reducing valve. Use one with a maximum reading capability (red needle) to determine maximum pressure over a period of time. The red needle is pushed up by the black needle that actually indicates the pressure. This photo was staged – the house is really on well water.

Domestic Piping Systems

There are failure issues with domestic piping systems that can cause leakage that may inadvertently be assigned to an appliance failure as the failure may be in the vicinity of the appliance. These failures can be related to the piping material as well as to installation issues as discussed later. There are different piping materials in service that the forensic engineer should be aware of.

✦ Copper Pipe and Fittings

Copper piping is and has been widely used but is subject to corrosion issues where water has certain chemistries. Most typically, we find pinhole leaks due to *pitting corrosion*. Alloy fittings can also suffer from *dezincification,* a form of corrosion that causes significant loss of strength of the material. The piping and fittings are also subject to freezing. Copper piping is traditionally joined by soldering, but push-on fittings are now available.


Photo #4 – Pitting corrosion in copper pipe.

Photo #5 – The pinhole leak from pitting corrosion can lead to a significant leak if not detected quickly, as the pipe erodes due to the high velocity flow. The entire piping system in this house was affected by a water chemistry problem.

Photo #6 – This is a valve with cracking that results from dezincification.

Photo #7 – This is a long-term failure and alloys with greater than 15% zinc content are very susceptible to this form of corrosion. It occurs often when the water has high oxygen and carbon dioxide content.

Photo #8 – Dezincification. The white material is zinc oxide that has leached from the alloy. The material has lost substantial strength.

Again, if a leak has developed near an appliance, it is easy to blame the appliance.

✦ CPVC (Chlorinated Polyvinyl Chloride)

This material is brittle and is connected with similar material fittings and bonded with a special solvent cement. The solvent is colored so that its application can be inspected. The biggest fault that I have seen with CPVC is that it is highly susceptible to freezing. It is not as labor intensive as copper.

Photo #9 -- This a section of CPVC pipe that froze in service. You can identify it by the solvent required and by its rigidity. This is not PVC as commonly used in drain lines.

✦ **PEX (Cross-linked Polyethylene)**

PEX is a flexible piping material that is connected using copper crimp rings. It installs quickly and easily, is not highly susceptible to freezing (it expands when subject to freezing) and has been use in Europe for domestic piping applications for many years. Today it is turning out to be the material of choice, displacing copper due to the high material cost and installation labor costs of copper. You can easily recognize PEX as it is typically either red (hot), blue (cold) or white and is flexible. I think PEX is by far the best choice of all piping materials. Issues have largely been with the use of metal fittings (dezincification) and not due to the PEX material. Recently plastic fittings are typically used instead of metal. Check the metal fittings and valves in the vicinity of the appliance.

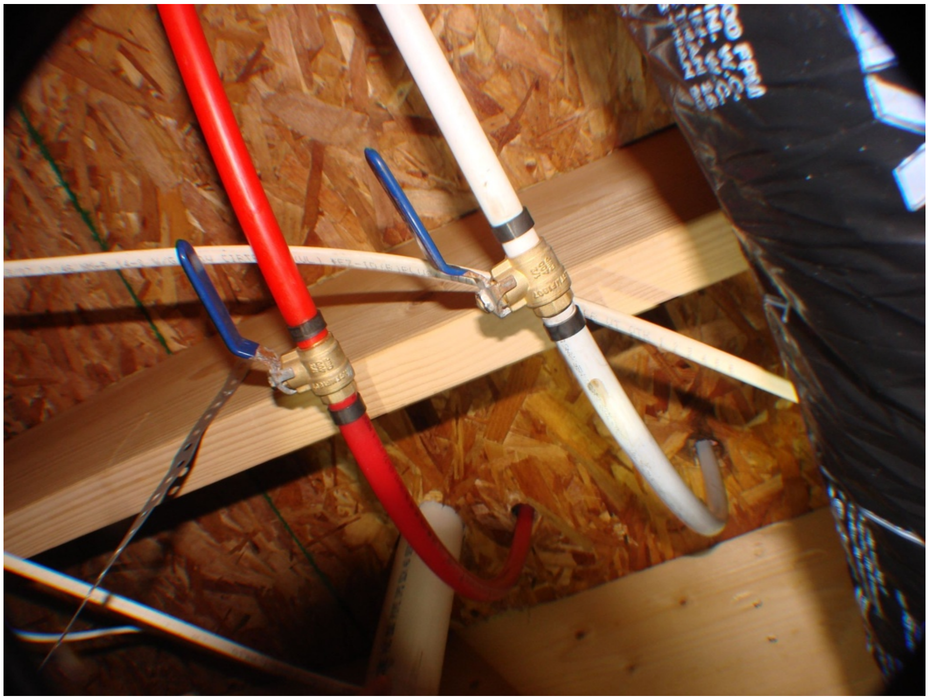


Photo #10 -- This is PEX tubing. If colors are used, red means hot, and blue means cold. However, coloration is not required by code and all piping can be white or clear. There are very few issues with PEX.

✦ **Polybutylene (Quest)**

Polybutylene (Quest) piping was widely used in the late 1970's through the mid 1990's. This proved to be a poor material choice as pinhole leaks in the material itself and leaks at the crimp rings developed in service. A very large class action suit (now closed) resulted in replacement of the piping in thousands of homes across the country. Many systems were not replaced, and we still find lots of polybutylene in service today. A pinhole leak in the wall behind an appliance can lead to the assumption of an appliance failure. If you see polybutylene, use extra care to make sure that the polybutylene is not the issue.

Photo # 11 -- This is polybutylene piping. It is always the gray color and is subject to pinhole leakage, as was this case with this pipe in a confined space.

Water Inlet Valves

Solenoid operated (SOV), normally closed, electrically powered inlet valves that are basically a commodity product when used in most pressure boundary appliances. The SOV inlet valves in dishwashers, refrigerators, and washing machines are very similar. Solenoid valves are not used strictly for appliances, and are widely used in critical applications, including critical systems in nuclear power plants, in aviation and in industrial and scientific applications. There is a big quality and reliability difference between a \$20 appliance inlet valve and a \$5,000 critical service valve.

The inlet valve is probably the most common failure in major domestic appliance water losses and is virtually the first place to look with high volume water flow failures, especially overflow conditions. Because the SOV in this application is normally closed, it takes an electrical signal to open it and withdrawal of the signal to close it. The valve is pilot operated and the pilot orifice is held in its normally closed position by a spring loaded plunger.

Often the cold-water inlet valve is ganged in multiple sections, with a common body but separate upper body sections and separate solenoid actuators. A diaphragm assembly provides the seal for the main valve seat. When the pilot orifice of the valve, which is controlled by the solenoid plunger, is closed, the fluid pressure builds up on both sides of the diaphragm through several bleed orifices (holes in the diaphragm). As long as there is a pressure differential between the inlet and outlet ports, a shut-off force is available by virtue of the larger effective area on the top of the diaphragm. The spring does not directly hold the valve closed. When the orifice is opened via actuation of the solenoid and upward movement of the plunger, the pressure is relieved from the upper side of the diaphragm. The greater effective net pressure force from below raises the diaphragm and opens the main seat of valve. Closing of the plunger is accomplished by shutting off power to the solenoid, which allows a force from the contained spring, which is sized sufficiently to overcome the relatively small pressure through the pilot orifice, to close the pilot orifice. This enables the pressure differential to once again hold the diaphragm and main seat shut.

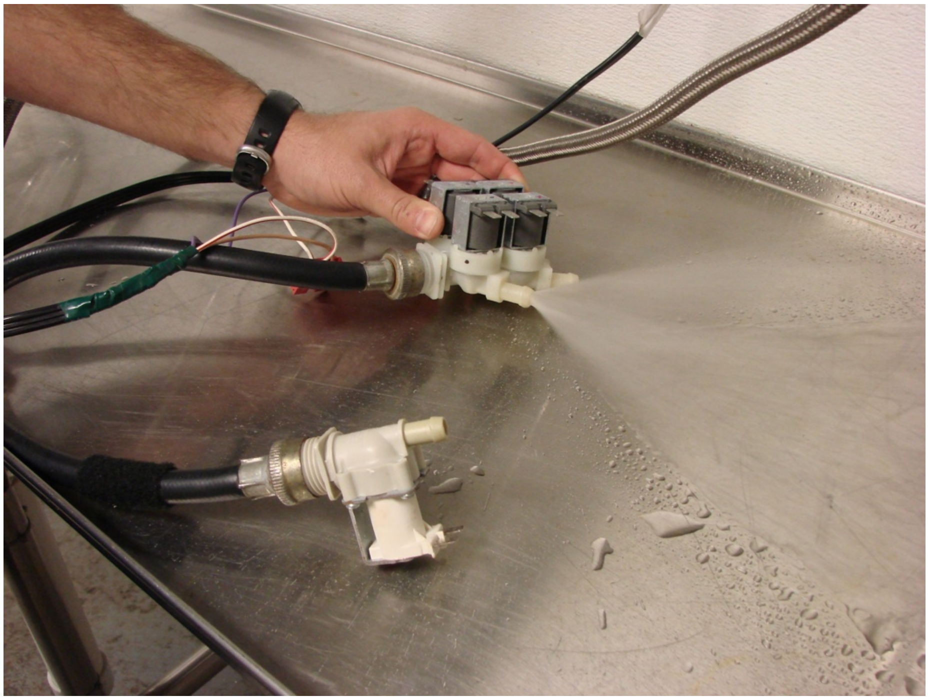


Photo #12 – A ganged solenoid inlet valve set being tested.

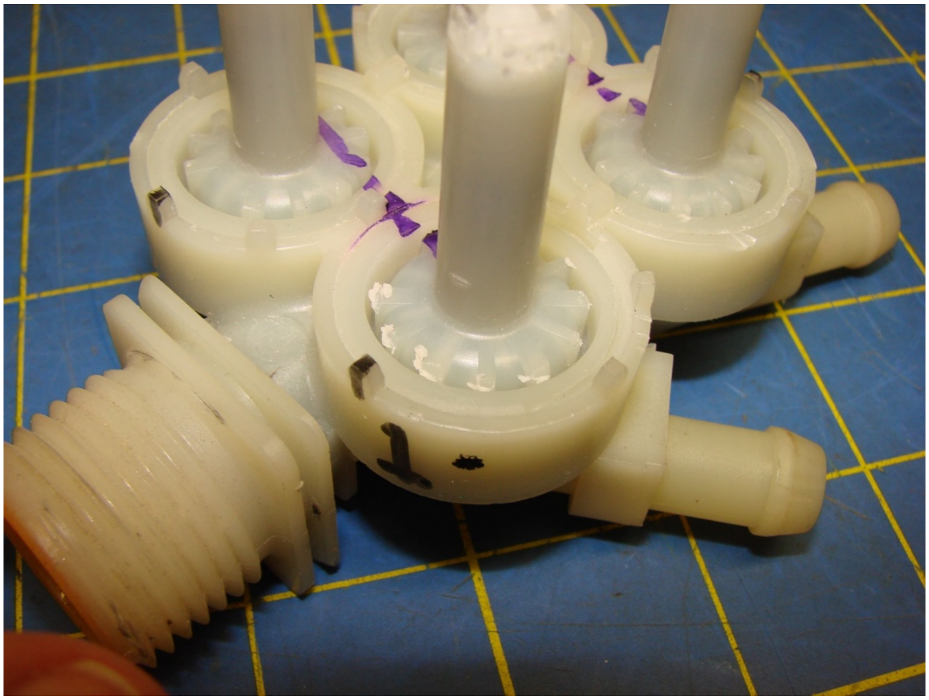


Photo # 13 -- The solenoid has been removed, exposing the valve body. The upper body screws off.

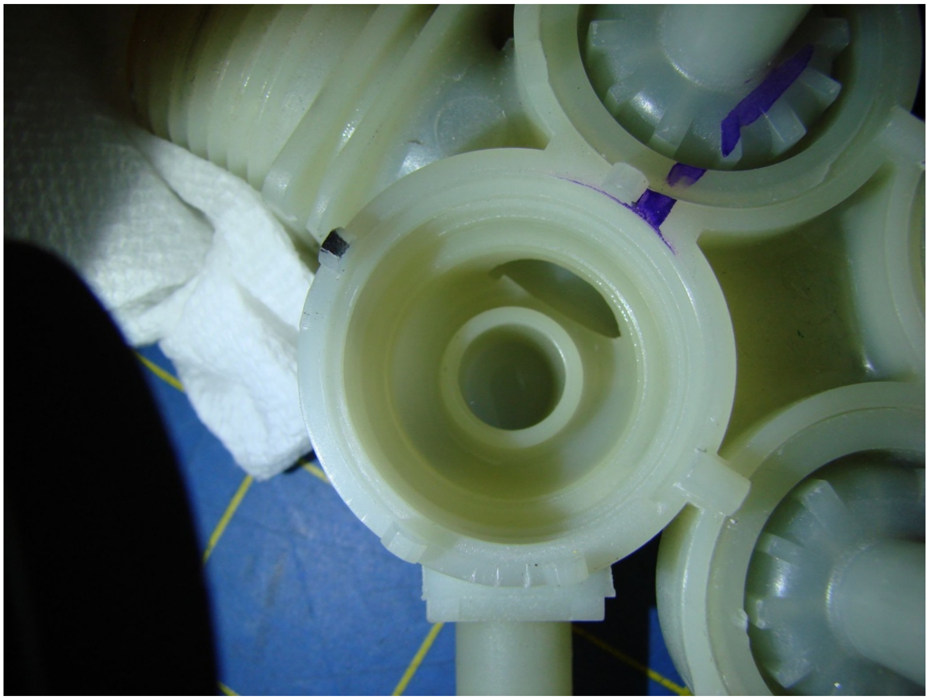


Photo #14 -- The upper body, including the plunger, spring and diaphragm assembly has been removed, showing the lower pressure retaining body and seat of the valve.

Photo #15 -- The diaphragm assembly. Note the bleed orifices surrounding the purple tip.

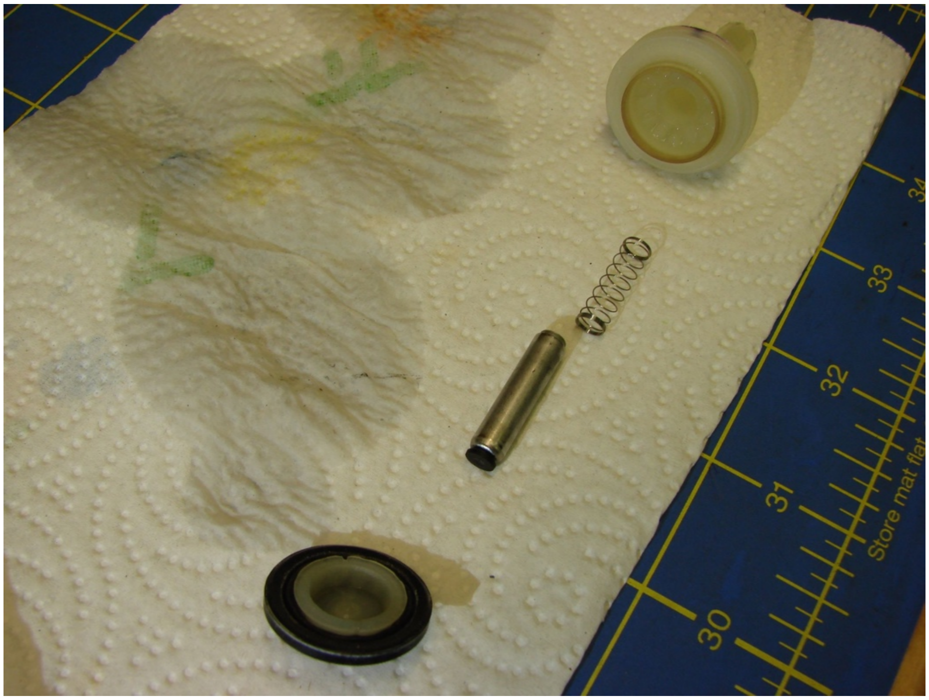


Photo #16 -- The parts of the upper section of the valve, diaphragm, plunger, spring and upper body. The tip of the plunger is rubber and seals the main orifice.

Attachment A contains a very good visual and written description of the function of the inlet valve, courtesy of Appliance411.com.

You can very simply test the valve to see if it is stuck open or defective by applying water pressure without the machine being plugged in. If water flows, the valve is stuck open or has failed open. Visually, you can usually see water staining or debris on the valve body if the valve has been leaking. Running the machine with an eye on the valve will tell you quickly if the valve is leaking or if the leak is at a connection to the valve. The solenoid of the valve can be tested electrically for continuity with a multimeter, but that will only tell you if the solenoid winding itself is bad (shorted). The electrical resistance (ohm) reading can also be determined and compared to the specifications. With a water leak event and a normally closed valve, a bad solenoid should not matter as the valve will not open if shorted and the water will therefore not flow.

Pressure Sensors/Water Level Switches.

Just as the inlet valve needs a signal to open, it needs a signal or interruption of signal to be shut off and to close. In washing machines, this signal depends on a diaphragm operated switch that operates on air pressure rise through a tube attached to the base of the tub or drum of a washing machine. If something does go wrong with the air pressure indication or with the diaphragm switch, the inlet valve will not close and one typically then has an overflow condition of the tub. We will discuss this more when we get to washing machines.

Drip Pans

Drip pans under washing machines or water heaters are nice, as long as the water loss is a drip. Anything more than that and the pan, even a drained pan, will be insufficient to control the water loss. There should never be water in the drip pan, and if there is it should not be ignored.

The Water Supply Connection

All water pressure boundary appliances must be connected to the domestic water supply in the home. How this is done varies, but this connection is often an issue. There are various type of hoses and tubing available and in use, depending upon the appliance. Dishwashers normally have a hot-water takeoff under an adjacent sink that is connected either by copper or plastic tubing to the inlet valve of the dishwasher. Recently, use of braided stainless-steel rubber tubing has increased and this is good. Older plastic tubing installations tend to turn brittle and fail, especially if movement occurs. The run from the sink to the dishwasher can be torturous, especially if the tubing runs a great distance. I have found a leak from a dishwasher supply tube buried deeply underneath cabinetry across the kitchen from the dishwasher. Most plumbers today install an under-sink hot water stop valve with a branch specifically for the dishwasher connection. This valve aids greatly when used with a braided stainless-steel tubing because compression fittings and those little self-piercing stop valves are eliminated.

The compression fitting with the nut and ferrule traditionally has caused lots of problems due to improper installation. We see fewer of these today due to the shift towards braided hoses or to tubing with a factory attached screw type nut and a washer seal. As a general contractor, I prohibited my plumber from using compression fittings. The problem with compression fittings is that there are many ways to install them incorrectly. Most commonly, the tube is not pushed into the inlet or outlet to its full depth, and the ferrule then is tightened against the end of the tubing, failing to make full contact with the tube. The other issues are insufficient tightening, overtightening, and reuse of the ferrule and tubing.

Drain Systems

The issue with drain systems for washing machines is usually a blockage internal to the domestic plumbing, a poor fit between the discharge hose from the machine and the wall standpipe, or failure to secure the drain hose in the standpipe. If that hose is in too tightly, or is an incorrect size, air cannot escape the standpipe. If too loosely inserted, the reaction of the hose due to the water discharge can push the hose up and out of the drain line. The latter is avoided by a mechanical restraint, often a zip tie securing the hose to the adjacent faucet or a restraint designed for the application, sometimes provided by the manufacturer of the machine. Check to see if there was such a restraint in place. One can test the drain by sticking a water supply line from the hot or cold shutoff valve into the drain and turning it on. Watch carefully to avoid a repeat water loss.

Dishwashers normally discharge into a disposal. If the disposal is full of food waste, it may create back pressure and kick the drain line off the disposal nozzle if it was not properly secured.

"As-Found" Condition

Document the as-found condition of the appliance and its installation area. Note water loss patterns and coloration and determine the extent of the water travel. Use a probe (I like a #2 Philips screwdriver or my highly engineered car key for this). Look for deterioration of the wood subfloor and wall framing to aid in determining the time frame of the loss.

Kitchens now often have floating hardwood floors, and water will tend to easily run under those floors, typically towards the center of the room. The water can migrate a long way and its effects not be observed. Use a moisture meter on the floor in the living space and go under the house if possible to assess the extent of damage. If there is a crawlspace, go under to observe the subfloor and framing and probe-test different areas. Take photos of how far your probe enters the wood. Also look for mold and other damage, whether pre-existing or caused from another active leak. I try to check plumbing under each bath and kitchen area and it is surprising how many other issues are observed. In crawlspaces, while looking for a water leak, I have found major long-term structural damage from excess moisture conditions (ground moisture) or insect infestation. A disconnected dryer vent duct can cause structural damage over a period of several years (look for lint on the framing and floor) due to the moisture it adds to the area.

Identifying Subrogation Potential

One of the most important reasons a forensic engineer is investigating a loss is to determine if there may be subrogation potential against a manufacturer or installer. If so the insurance client will notify that party and request payment for monies paid to investigate and remediate the loss. The forensic engineering report is a key factor in success of this subrogation. Also, the engineer must be prepared to demonstrate why the loss occurred and produce the evidence of such if another party wishes to inspect it. Subrogation can lead to litigation, and the forensic engineer must be prepared to undergo deposition and testify several years after his investigation is complete.

A very important factor in addressing subrogation is the age of the machine and the duration of the Statute of Repose in the state. The forensic engineer should be aware of this statute before going to the site. If the machine is outside (beyond) the time limits of the statute, there is no recourse for subrogation, and it will not generally be necessary to take evidence or other actions related to subrogation in this matter. One can easily check the date of manufacture of the machine using the serial number and going either to the manufacturer website or one of several others that provide this information. If you think you have subrogation possibilities, research the model/serial number online and check the Consumer Products Safety Commission website for information on known defects and recalls.

PRESSURE BOUNDARY APPLIANCES -- THE DISHWASHER

Dishwashers are basically alike in terms of operation and configuration. Some are designed to be portable, but most are designed for undercabinet permanent installation. There are also variations in single compartment vs. drawer type multiple compartment units.

The tub is either of plastic or of stainless steel. The latter is more expensive but provides better protection against a leak caused by loose silverware contacting both the heater element and the tub. This of course is a mode of failure that is a user issue, not a manufacturer issue, but is fairly common.

Operation

Basically, the dishes are washed with heated water and dishwasher detergent. It is important *not* to use common liquid detergent intended for handwashing dishes in the sink, as this generates too many suds and a "suds flood" will result. This of course can be mistaken for a dishwasher leak.

The dishwasher heats its own water with a built-in heater element that normally penetrates the tub from under. This heater may also be used after the washing is finished to dry the dishes.

The cycle is rinse/wash/rinse/heat depending on how many options are provided by the particular dishwasher model. Water is drained into a sump and then pumped through the drain hose to the sink or more normally to a garbage disposal that has a nozzle to accept the drain hose. The drain hose in newer models is generally corrugated and should be installed with an anti-siphon loop or an air gap between the dishwasher and the disposal.

Manufacturer directions provide the installer with the proper routing of the supply and drain lines within the cabinet spaces. These are important to avoid kinking.

Water is typically circulated inside the tub by the same pump that drains the machine and is sprayed through sets of rotating arms onto the dish load. The dishwasher will have a float switch that shuts off the incoming water when the level reaches the set height. The sump screens out or chops up most debris.

The unit is controlled by a circuit board, with various sensors to determine the ongoing status of the machine. That circuit board is typically in the upper part of the door and is well sealed. Most mechanicals are in place under the machine, and there is an access panel at the lower front of the dishwasher through which a visual inspection can quickly be done to see if leakage is or has been present. Hose connections are generally made with clamps and are usually reliable, however losses do occur when a hose separates from a nozzle. The photos provide some examples.

Water Connections

The water supply is typically via a ¼-in or 3/8-in OD tube attached to the hot water supply line under the sink. The sink end is usually buried under stored items near the sink floor and may leak for a long time without being noticed. The dishwasher end connects to the inlet valve under the machine. This connection is not visible to the user without removing the lower front access panel. The installer makes this connection and it is often the source of the leak, especially if it is made with a compression fitting.

The drain tubing is provided with the dishwasher. The dishwasher-end connection of the drain tubing is made at the factory and is reliable. The drain tubing will connect to the under-sink drain or to a disposal installed under the sink. The disposal connection is made by the installer and is usually a stainless-steel screw clamp on a manufacturer-supplied flexible rubber fitting.

Most Common Losses

The most common dishwasher loss is probably one related to the inlet valve, either a bad inlet connection or leakage of the valve, which normally shows up through the intersection of the valve body with the solenoid assembly. The outlet of the inlet valve is a factory clamp fitting to a rubber tube that is reliable. The inlet valves are made by the thousands and are not always of good quality. It is my impression that the more expensive the machine is the better the inlet valve. If the float switch fails, the incoming water will not stop flowing. I have never seen a failed float switch, usually the inlet valve itself is bad. One can electrically test the float switch with a multimeter if necessary.

The second most common loss in my experience is failure of the seal between the sump and the rotating shaft of the pump assembly. This shows up as water and soap staining on the exterior of the pump assembly. There are also possible losses from the diverter in a single pump machine. The diverter directs the pump flow either to the drain as waste or to tub for recirculation during the wash.

Certain less expensive machines often have a poor design where the heating element passes through the tub, and this connection is a point of failure. Additionally, a metal utensil that gets loose in the machine can fall across the heating element and burn a hole in the plastic tub of the machine, leading to an immediate water loss. Look here if soapy water is suddenly lost from the machine. The utensil will not typically damage the stainless tub models.

The door gasket can sometimes get out-of-position or wear causing leakage through the lower part of the door. A stuck open inlet valve may show up as leakage through this gasket as the water in the tub rises.

The Inspection

If the machine is in place under the cabinet, first find the manufacturer nameplate. It is usually on one edge of the door. Photograph it closely so that the model and serial numbers can be read and put the photo in your report. Then visually inspect and photograph the interior of the tub and the exterior front of the machine. On the interior, look particularly at the door gasket, and at the heater element penetrations. Look for burn marks on and under the heating element. A tub perforation or crack is rare but can occur, especially in a plastic tub. Remove the access panel and look under the machine with a flashlight. Take a few photos under the machine. The inlet valve is often at the left front. You can normally see part of it but not all. Look for water staining and signs of a water leak in this area. If you do not see a source of water under the center of the machine, then it should be removed for closer inspection and testing if necessary. You can test it in place (pull it out a bit from under the cabinet) but visibility is limited and you can generate more water on the floor if the machine leaks.

If the machine has already removed from its installation location, photograph it from all sides. Document the condition of the supply hose and its connections if it has remained attached. Document the condition of the drain hose as well. The machine can be placed on its back for visual inspection of the underside mechanicals. Don't forget that there is water remaining in the sump that will run out onto the floor.

Shop Testing

If this was a high volume leak it is likely the source can be identified from water staining and soap residue. If not, test the machine. This testing is best done in the shop, so it is best to have taken it into evidence for testing and do it there. If the homeowner will not release the machine, it can be tested on site using a garden hose and a few fittings. I carry an extension cord with the end cut off so that I can attach it directly to the machine. If you run into a Bosch machine, they are often set up with a special electrical cable that is inserted into a jack on the machine. You will need that cable, which is intended to feed from an electrical box mounted in an adjacent cabinet.

First, apply water pressure to the inlet valve but do not power up the machine. If water starts flowing into the tub, the inlet valve is defective. If no water flows, operate the machine through several different cycles and see if it leaks. The photographs following show typical failures that I have come across. Some machines have self-diagnostics and error messages. The latter are often defined in the user manual and are always in the service manual. These may help. Some of the machines have a complete use history stored in them, but this is accessible only to select personnel, usually those from the manufacturer. These are like flight recorders and may record every use and every fault or error message.

If a forensic engineer has a machine that falls within in the Statute of Repose period, do not take assemblies or subassemblies apart to find that leaking seal. The manufacturer will not accept a subrogation where the part has been subject to disturbance or destructive testing (*spoliage*). If he wants to see the machine, that can be arranged directly with him after the insurance adjuster notifies the manufacturer. If the manufacturer wants the defective part shipped to him, send the entire assembly. You can remove the inlet valve but cut the outlet hose near the valve and leave the inlet tubing attached if it was attached when you found the machine. Hopefully the restoration contractor knew enough not to disturb that inlet valve connection. If there is a leaking seal, the entire sump and pump assembly will eventually have to removed and shipped to avoid spoliage issues.

You can open the door assembly to look at the circuit board, but about the only thing you may be able to see are burn marks from an electrical failure, and that is not very likely. You can check all connections, but typically a defect in the control board that causes a leak will require laboratory testing to identify. If the machine runs normally and does not leak, then the service manual typically tells you to replace the circuit board. If you can get a copy of that manual it will help.

PHOTOGRAPHS – DISHWASHER EVENTS

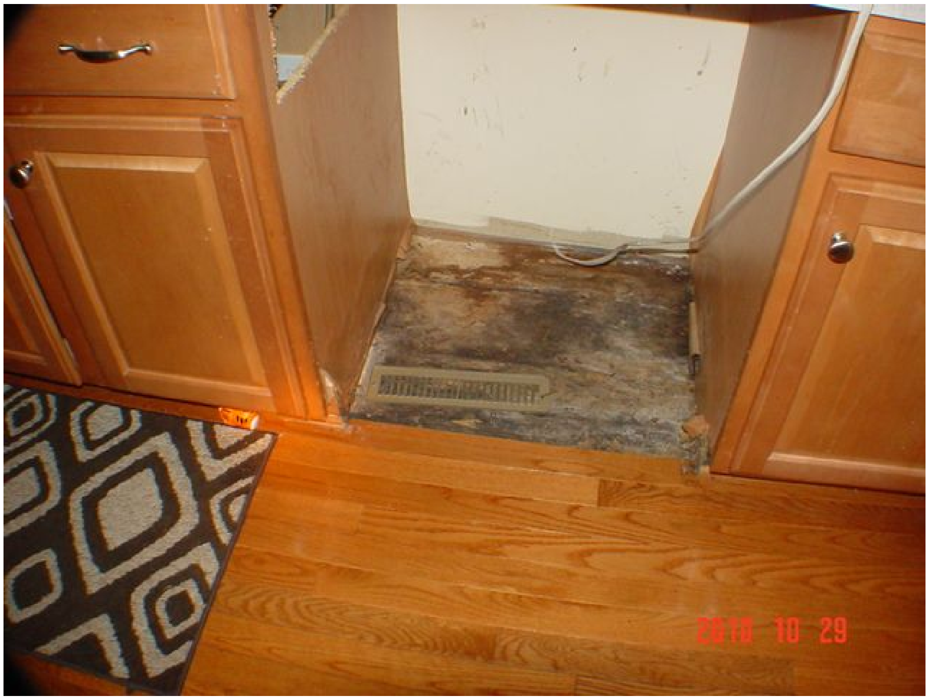


Photo #17 – Typical water staining left after a dishwasher leak. We need to determine the time frame of the leak and this staining assists us in doing that.

Photo #18 – The water from a leak tends to run under the finished floor towards a low part – usually the center – of a room.

Photo #19 – The heater element in a dishwasher penetrates through the bottom of the tub. These connections show discoloration, but underneath…

Photo #20 -- …there is a bit more damage.

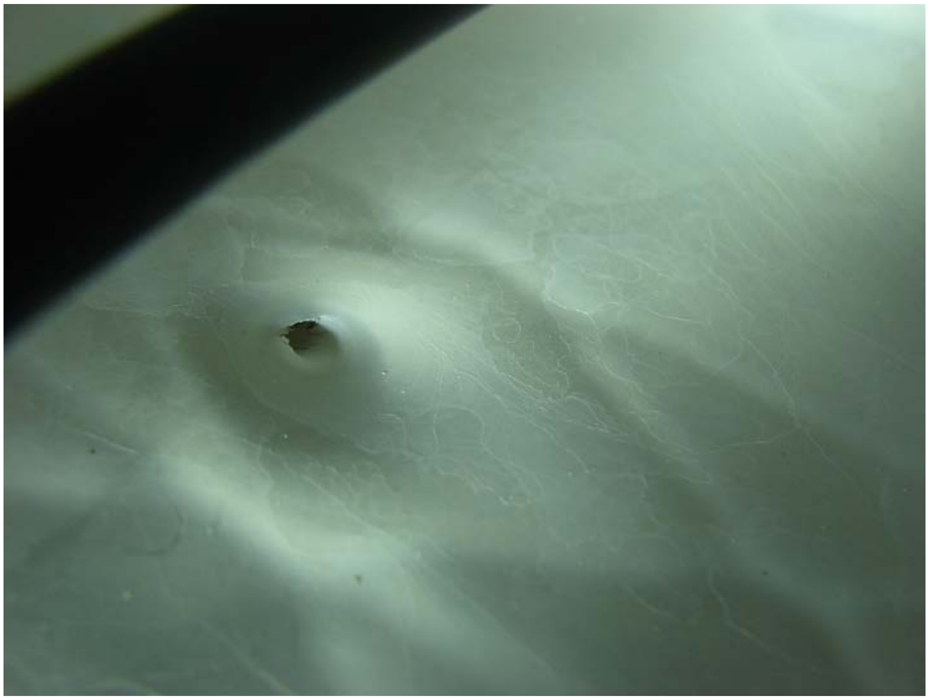


Photo #21 – This hole appeared in the floor of the tub, likely from excess heat from the heating element above. It is possible that a loose utensil contacted the element and the tub.

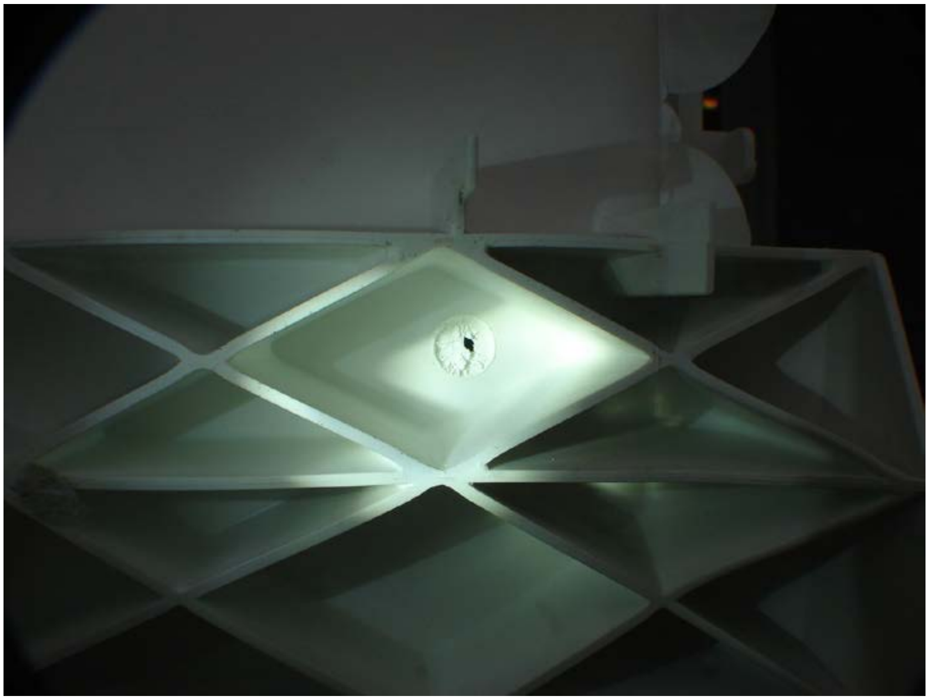


Photo #22 – From under, there was a post supporting a metal reinforcing strip on the underside of the machine.

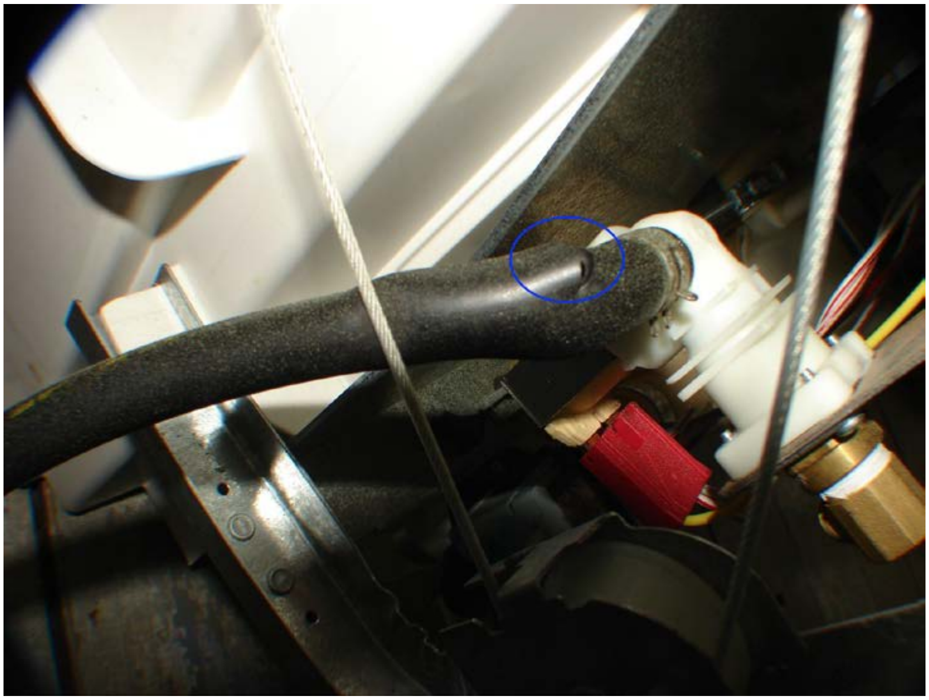


Photo #23 – This water outlet hose from an inlet valve got caught up in the door hinge assembly. The inlet valve had been changed and was installed to put the hose in an improper orientation.

Photo #24 – This drain hose was at first thought to have been improperly run in the cabinet and kinked. Later we found that a caustic substance was likely associated with use of the dishwasher.

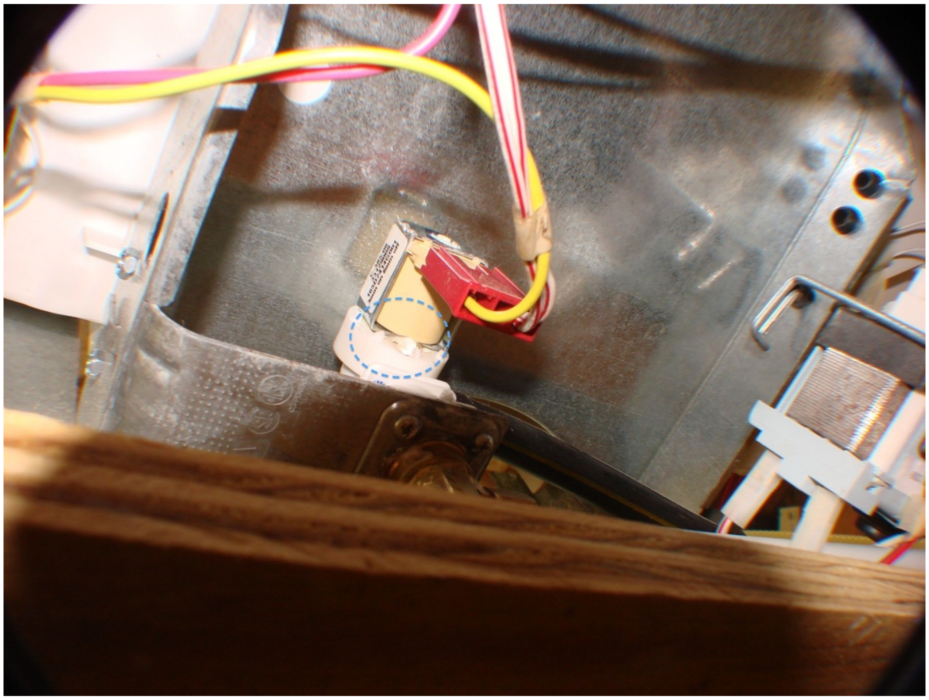


Photo #25 – An inlet valve leak between the solenoid (yellow) and the body (white) of the valve.

Photo #26 – Another similar leak on a different machine…

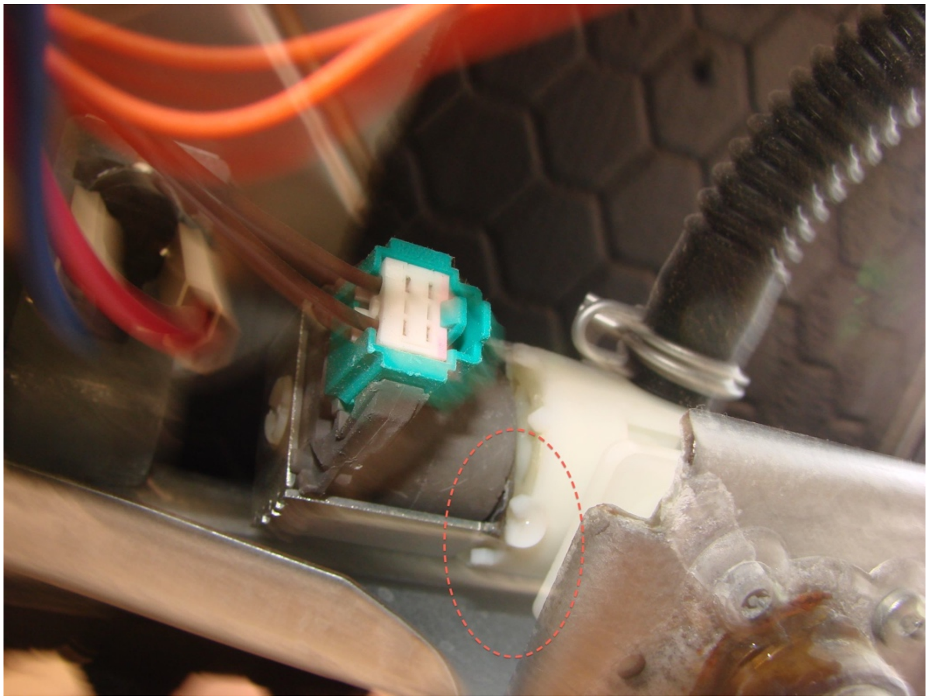


Photo #27 -- ...and another.

Photo #28 – This inlet valve leaked under water pressure with no power applied.

Photo #29 – This one leaked through a defect on the body.

Photo #30 – This is a test in progress where water flowed into the tub when water pressure was applied without powering the machine. This is a bad inlet valve that is stuck open or otherwise damaged.

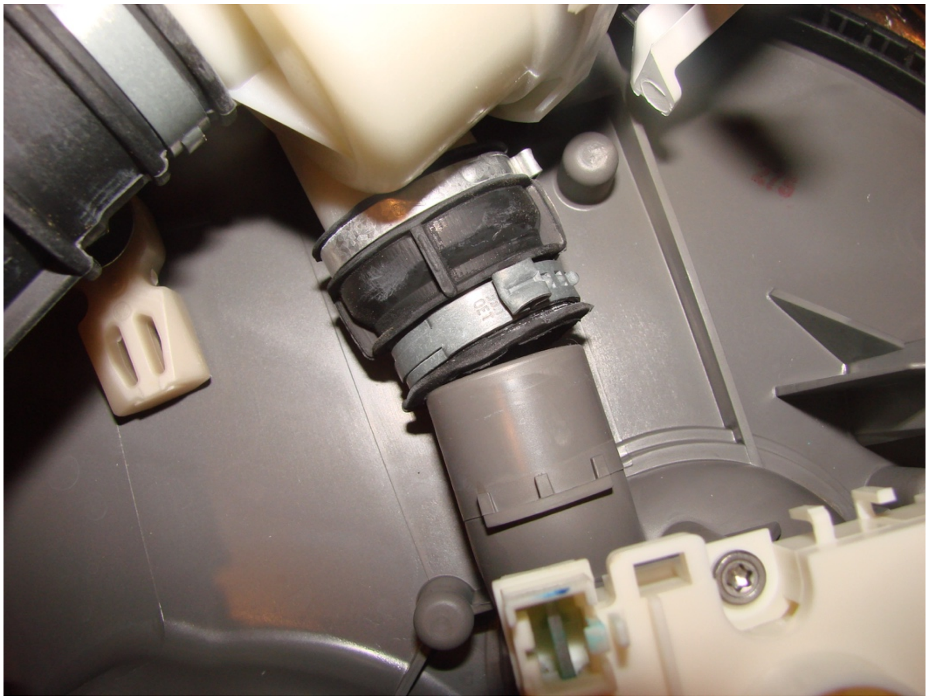


Photo #31 – This separation is a design defect in the connection. There is no resistance to axial movement.

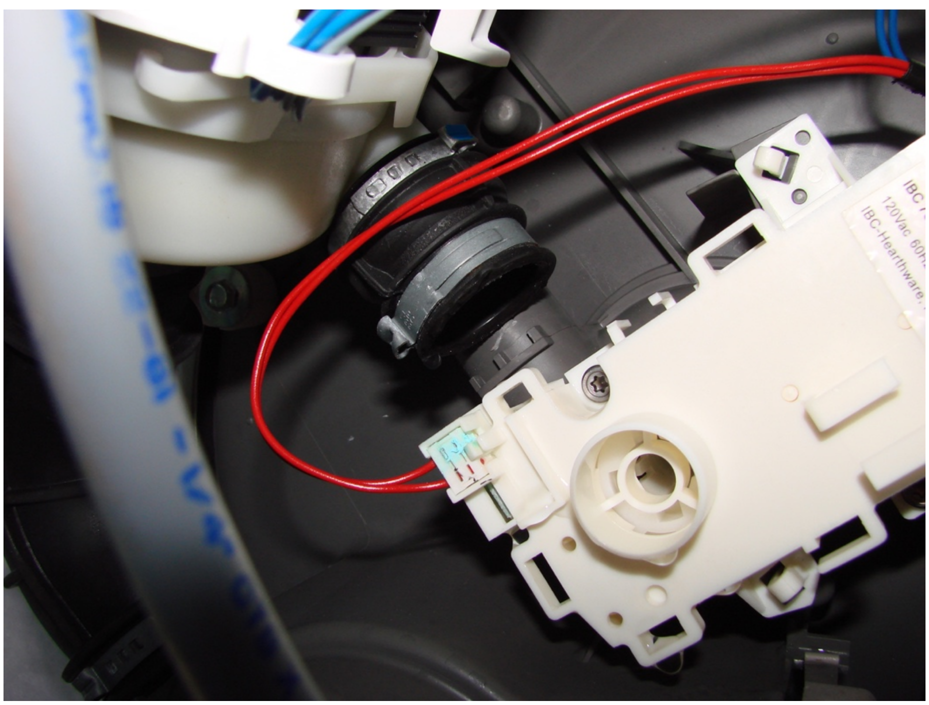


Photo #32 – This is another instance of the same issue. This is a manufacturer issue.

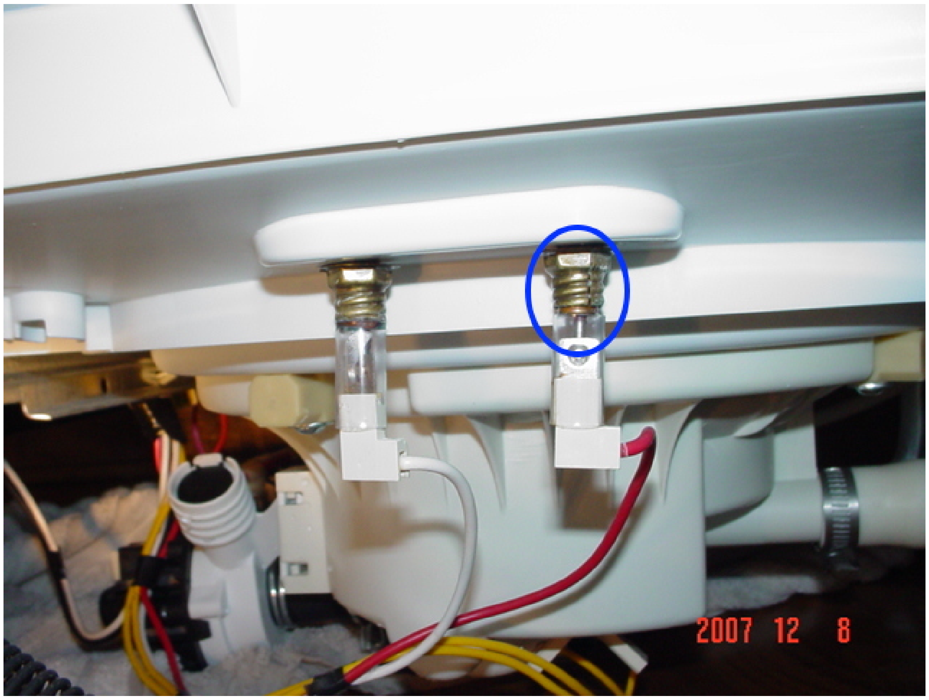


Photo #33 – This heater element penetration did not leak but the nut is cracked. The nut is not very robust.

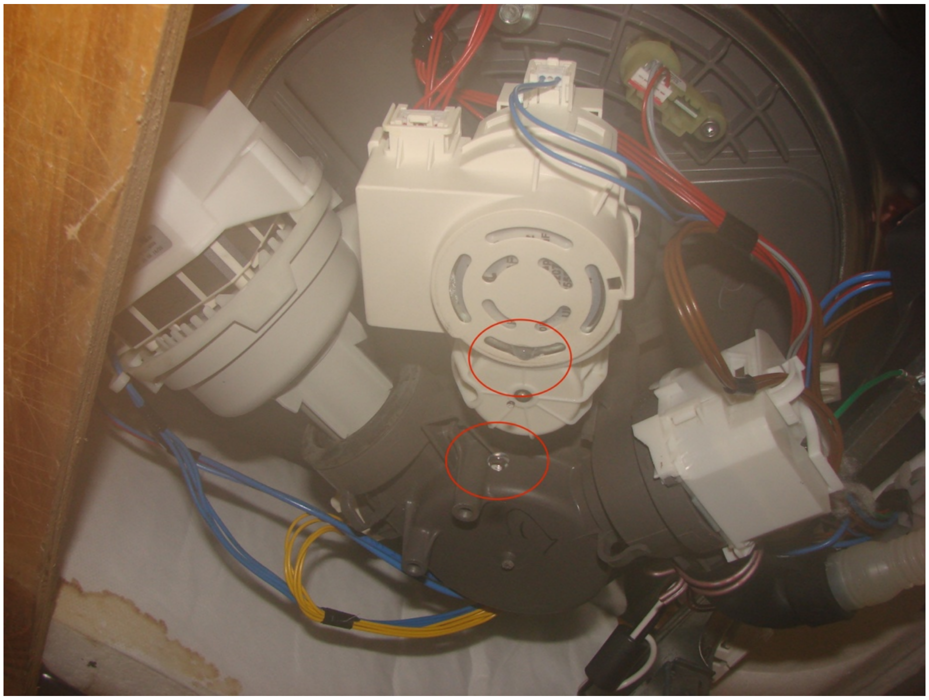


Photo #34 – A water leak from a diverter.

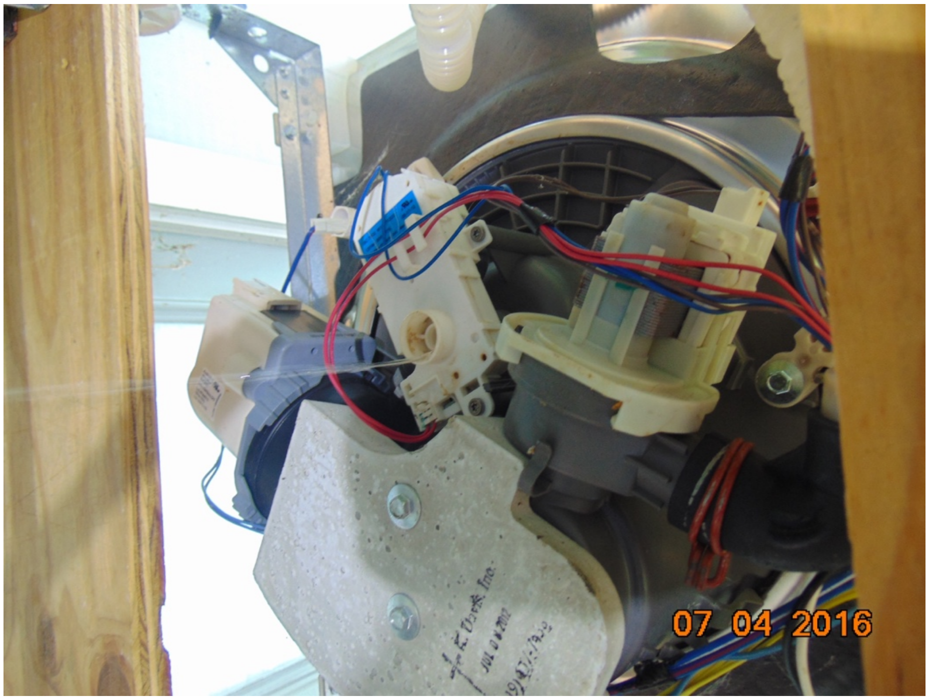


Photo #35 – Another water leak from a diverter.

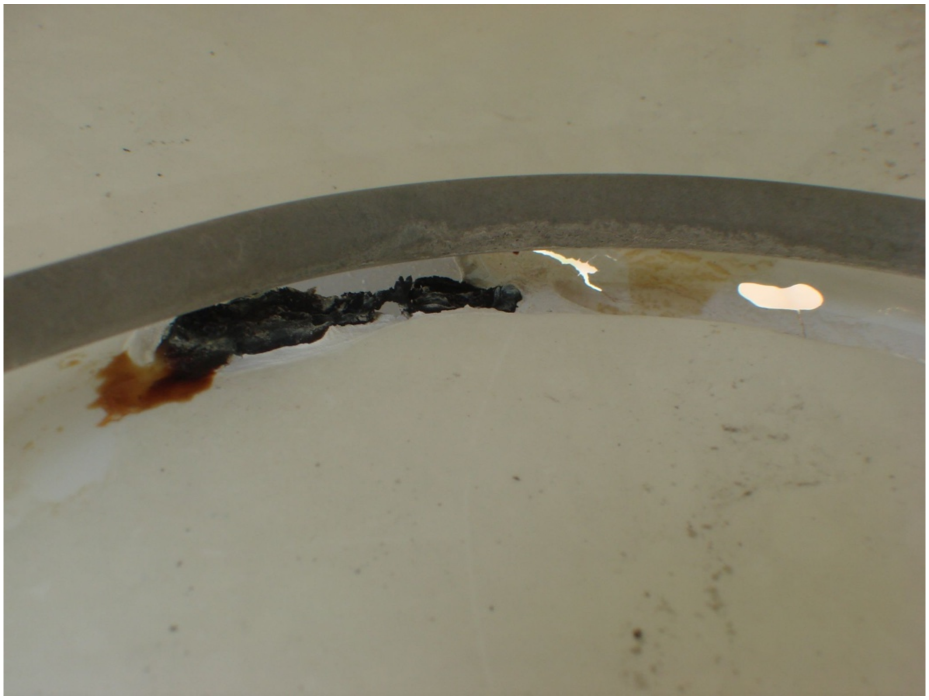


Photo #36 – Contact of a heater element with the plastic tub created a hole in the tub.

Photo #37 – This is the same instance in the previous photo seen from below. The heavy corrosion indicates a longer-term leak.

Photo #38 – A bad end on a water supply hose.

PRESSURE BOUNDARY APPLIANCES -- THE WASHING MACHINE

Washing machines are second to dishwashers in frequency of water losses. They are a bit more difficult to inspect and test due to the cabinetry and the simple fact that they have more complex systems.

Washing machines have two major types – top load and front load. Both machines are heavy and more difficult to move than dishwashers. With certain front loaders, there are shipping bolts that should be installed before moving the machine if they are available. Both top loaders and front loaders can have either a direct drive system or a belt drive system, but the drive system is not of great concern with regard to water loss issues.

Gaining access to the top loader can be a bit bewildering if you do not have a service manual. Usually the front has a couple of hidden clips between the top and the front or side panel that you can release with a putty knife, but some have an arrangement that lets you remove the front and both side panels as a single piece. The controls are normally in a console on the top rear. Often the console has a few screws attaching it on the back and will lift off as a single piece.

Most front loaders have an easily removable top (2 or 3 screws at the rear of the top and slide the panel to the rear). This allows very good access to the systems that service the tub, including the inlet valves. The rear panels either come off as a whole or have an access panel. The front panel and door assembly is also removable, but that takes a bit of work.

If you have issues with disassembly, the appliance part suppliers on the internet have exploded drawings and wiring diagrams and several have very helpful videos that demonstrate how to access and replace parts.

Operation

Operation depends upon the cycle selected, but basic operation includes fill, dispensing the detergent, wash, drain, rinse and drain, followed by a spin to force water out of the clothes and pumping to drain the sump. The wash in a front loader is done by tumbling the clothes, not by agitating them as in a top loader. The inlet valves are operated for fill and rinse. The front loaders spin faster than the top loaders and actually use less water per cycle than the top loaders. One thing to watch for is that the front loaders generally use a HE (High Efficiency) detergent because there is less water used in the cycle. Use of a non-HE detergent in a front loader can cause over-sudsing and potentially interfere with the mechanicals, including overheating the pump, during the wash.

There are either one or two pumps on the machine (drain pump and recirculation pump). If only one pump is present, there is a diverter of some sort that selects the drain or recirculation function. This diverter is integrated with the pump assembly and has been an issue for a certain brand of machine.

Water Connections

The supply water connections are hot and cold and are normally made from a wall box installed in the house by a plumber. Hoses are reinforced plastic or rubber, or rubber with stainless braiding. Female washer-type hose connections are at each end. Quality varies, but it is my opinion that the stainless steel braided hoses are best. At initial inspection, check the inlet valve connection for debris in the screens. Hot water lines are more apt to show debris as there is generally corrosion debris from the hot water heater. The debris can block passages in and disrupt the inlet valve if to much of it gets through the screen.

The drain hoses are supplied with the machine and are inserted by the installer into the drain standpipe in the wall box. Most are now the corrugated plastic type. These hoses should be secured at the wall box to prevent being forced out of the standpipe by the thrust of the discharging water and they must have an air gap at the standpipe.

Most Common Losses

Inlet valves are probably the most common losses. The inlet valve will either stick open, leak from a connection (typically the inlet connection), or leak from the intersection of the body and the solenoid. If the machine overflowed, it is likely a sticking or failed valve. If it leaks from under it is often a leak in the inlet valve or in a connection. Some front load washers have a ganged set of inlet valves (Hot, prewash, main wash and bleach). These service different compartments in the detergent tray. On these machines the inlets to the inlet valves themselves are all connected internally with factory clamps from the two external hot and cold lines and are therefore quite reliable as they these connections are not dependent upon installer installation.

The inlet valve depends on a signal from a diaphragm pressure sensor to shut off when the proper water height in the tub is achieved. This sensor is part of the water level switch control on top load units and is usually a separate switch on front loaders. If this switch fails, the inlet valve will not shut off and an overflow will occur. The sensor is really a diaphragm switch that depends on an air pressure increase as water rises in the tub. The air volume is connected to the switch with a plastic or rubber tube. If the tube leaks or debris blocks the air inlet (air chamber) assembly, the switch will not work. I have found several top load machine failures due to air tube blockage. This blockage is more apt to happen if the machine is used often for very dirty clothes (work clothes) or to wash diapers (not so common nowadays). On most top load machines, the tubing and air chamber is clear plastic and blockage can be seen visually with the aid of a flashlight.

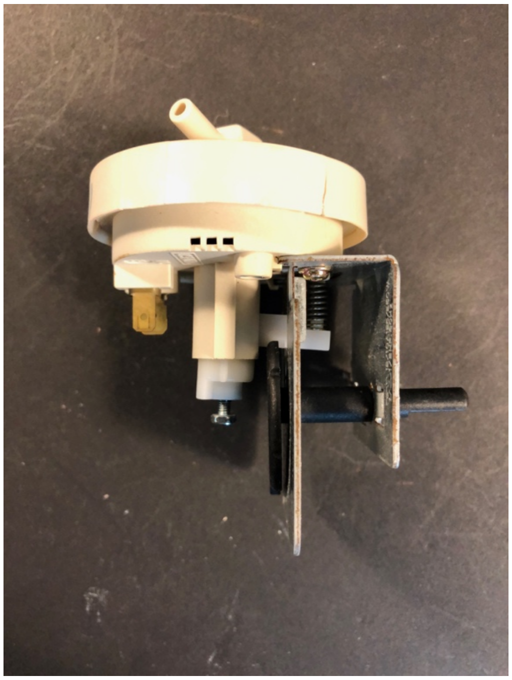


Photo # 39 – A typical pressure sensor/water level valve for a washing machine.

Photo # 40—This mechanism adjusts the set point as one rotates the selection valve to different cycles that are associated with different water heights. The black shaft is rotated by the used to select the cycle. The shaft wheel is configured to set the contact distance.

Photo # 41 – The pressure switch internals.

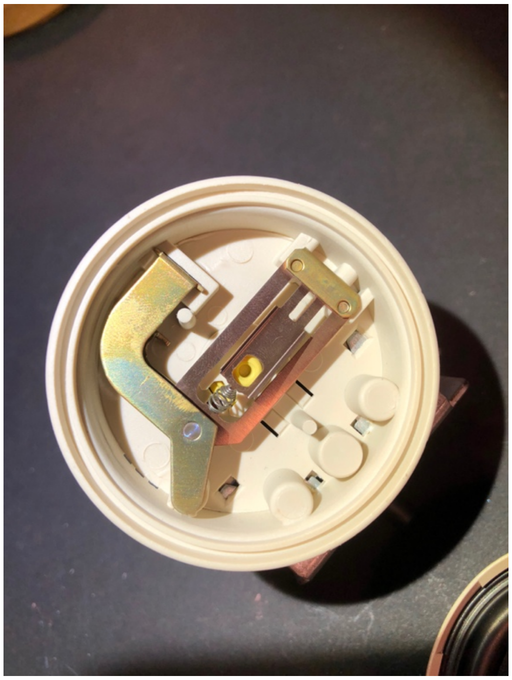


Photo # 42 – The electrical contacts are adjustable.

Photo # 43 – The diaphragm and the plunger. The diaphragm moves down as the water fill increases the pressure above the diaphragm to make contact at the adjusted set level of the switch.

Photo # 44 – At the other end of the system is the air dome and tube connection to the tub. As the water level in the tub increases, the air pressure in the tube increases.

:

Photo #45 -- On certain front load machines there is a filter housing on the lower front panel. This plastic screw fitting was loosened without draining the sump to show that there is water remaining in the sump after a wash. Note small hose to the left that pulls out and would be used to drain the sump prior to opening the filter.

Photo #46 – This is the filter. It will catch any small clothing items that escape the drum or whatever was left in the pocket of those jeans before the wash. I had one case where a guitar pick blocked the drain just inside the filter cavity.

On front loaders there is not a separate internal fiber filter element, but this device is designed to catch larger items that get through the wash that might damage the drain or recirculation pumps. The user is instructed to clean this filter regularly. Cleaning involves draining the sump with a small hose provided and opening a plastic screw fitting access to the filter. There have been a number of cases where the access fitting is not properly replaced, and a leak occurs through the access fitting. Users are sometimes reluctant to admit that they put the access back improperly; therefore, if there is an otherwise unexplained one-time leak, the forensic engineer may look to this condition.

On the front loaders, the gasket that attaches to the tub and the front panel can be compromised (holes or cuts) and can leak. This will show up quickly in testing. These gaskets are held in place by hidden spring wires (see the photos later in this section). I have seen at least one case of a retaining spring wire failure that caused a leak.

I have also seen a case of spring failure of the larger spring that supports the struts that in turn support the tub. This failure allowed the tub to fall on one side, pulling the air tube for the pressure switch out of the tub and causing the leak.

Testing

Interview the user if possible to determine what happened and where the water came from during the leak if possible. If you can determine that it was an overflow event, that provides a good head start. I prefer to do onsite testing if possible due to the difficulty of moving these heavy machines, although I won't do it in living spaces, especially in a second-floor situation. Most often I find the machine already relocated to a garage, and it can be easily tested there. If there are issues preventing this, the machine is taken to the shop for testing. If a manufacturing defect is found, the machine should be taken into evidence.

Check the plumbing wall box for indication of a valve leak or a drain backup. Following that, a thorough visual examination and opening the top and/or front panel will often identify the issue. The visual examination and simple pressure testing of the inlet valves without powering the machine will very often indicate an inlet valve leak or failure to close. The pressure switch air tube and air chamber can be visually inspected. The top load machine can be tipped back against a wall and the mechanicals under visually inspected. Look for water staining, corrosion, and soap residue. Look for separated hoses or holes in the sump.

Failing this, operate the washer. Hot water may not be available, but there is a double Y-fitting hose and valve assembly available at home stores that will accommodate a garden hose input, with two outlets for the hot and cold water to the machine. The fourth hose input can be capped or used to connect a pressure gauge. I start with a light or short cycle and progress to longer cycles if necessary.

Photo #47 – This is the rig I use to remotely test a washer.

If the service manual is available, run the built-in diagnostics. If no leak appears during several cycles, the service guides most often recommend changing the circuit board. While this may be an explanation for a failure to close an inlet valve, a circuit board malfunction would not typically cause a leak if the pressure boundary is intact. If water backs up there may be a blockage in the sump or drain pump, or the drain pump may not be working. Otherwise, a blocked drain piping (standpipe) or downstream blockage (toilet blockage) can be investigated by running water into the standpipe.

Sometimes, the machine just won't leak again.

PHOTOGRAPHS – TOP LOADERS AND WASHING MACHINE EVENTS

Photo #48 – This view of the rear of a front load machine shows the access panel and the hot/cold water inlet connections.

Photo #49 – The hot and cold inlet screens should be checked for debris. Debris may get through and affect the operation of the inlet valve, which has small internal passages.

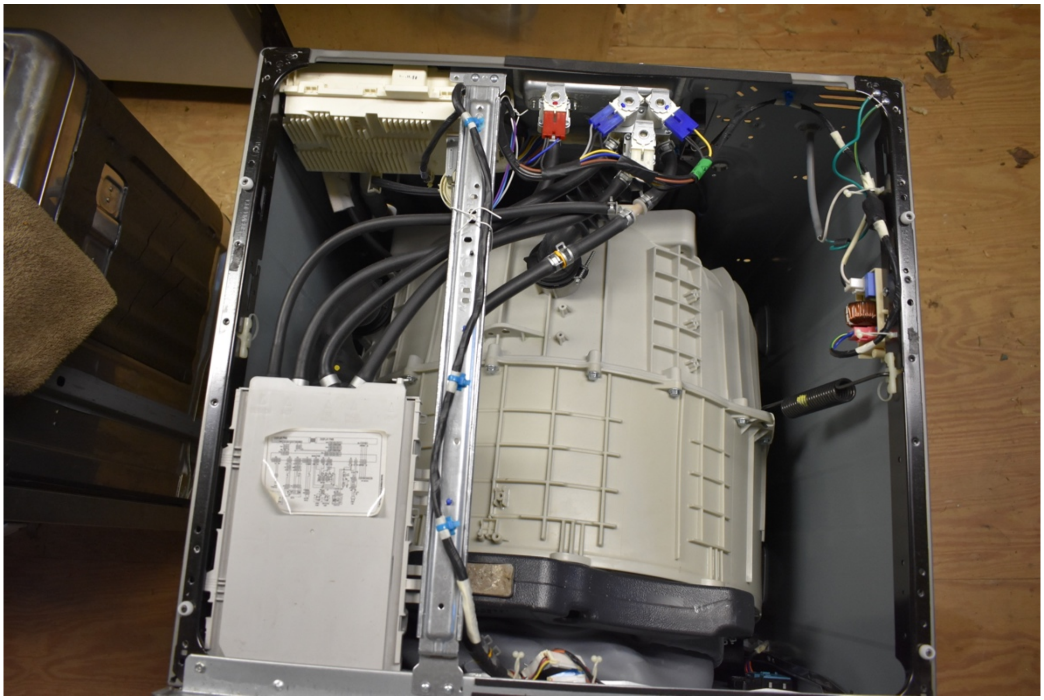


Photo #50 – Removing the top of a front load machine exposes the drum (tub), the electronics (circuit board) package, the detergent dispenser and the noise filter (on the right).

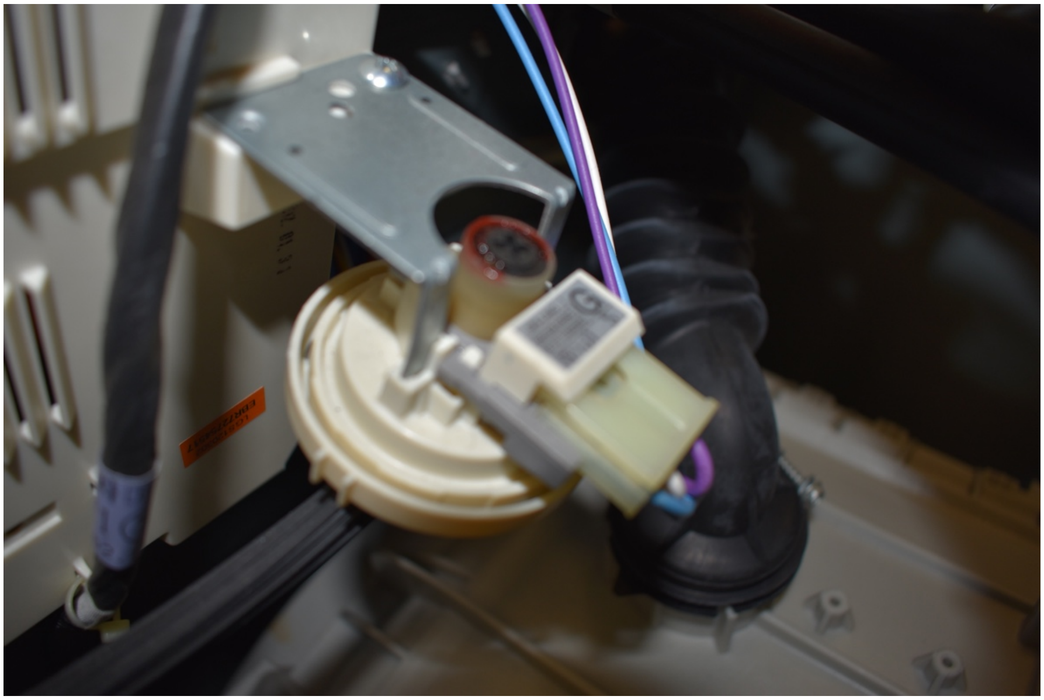


Photo #51 – The pressure sensor shuts off the inlet valve when the water reaches a set level. This is located under the support brace if the photo above.

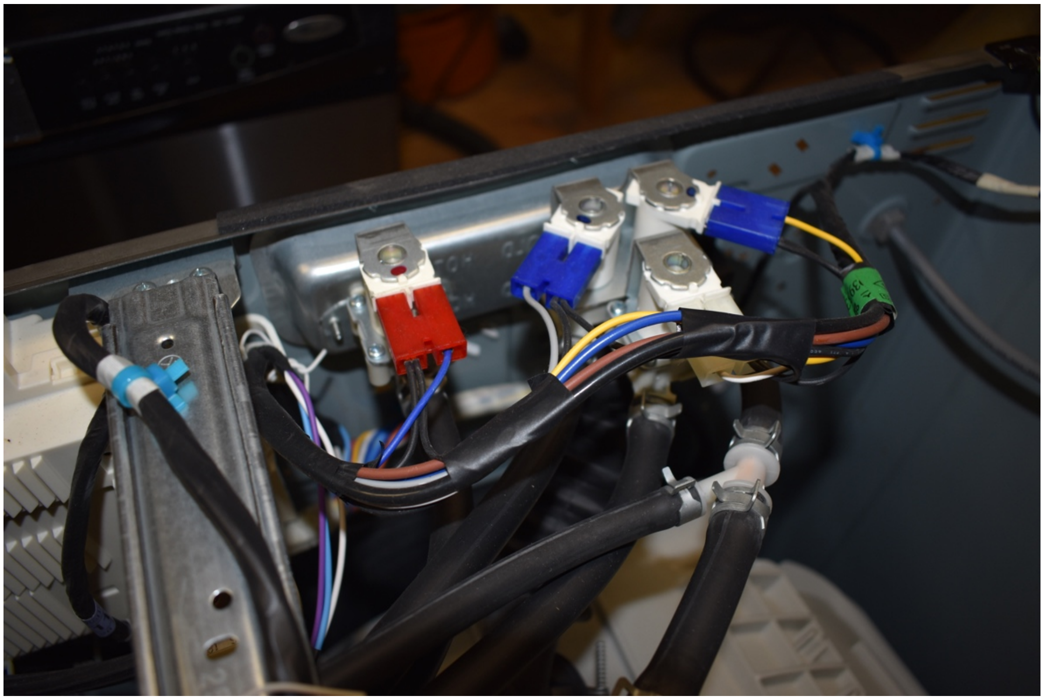


Photo #52 – This machine has four inlet valves. One is hot water and the others are cold water run through different sections of the detergent dispenser.

Photo #53 –The gray gasket connects the drum to the front panel of the machine. This can fail due to mechanical damage or the spring wire that attaches it to the machine can fail.

Photo #54 – The spring wire is hidden. There is one on the front panel and another on the drum.

Photo #55 – The detergent dispenser drawer. The inlet valves run cold water through these compartments and into the tub at different times in the cycle.

Photo #56 – On a top load machine, the top or side latches are often hidden. Pushing a putty knife in a little does the job.

Photo #57 – Opening the top of the machine exposes the tub and agitator. The inlet valves are at the top of the photo.

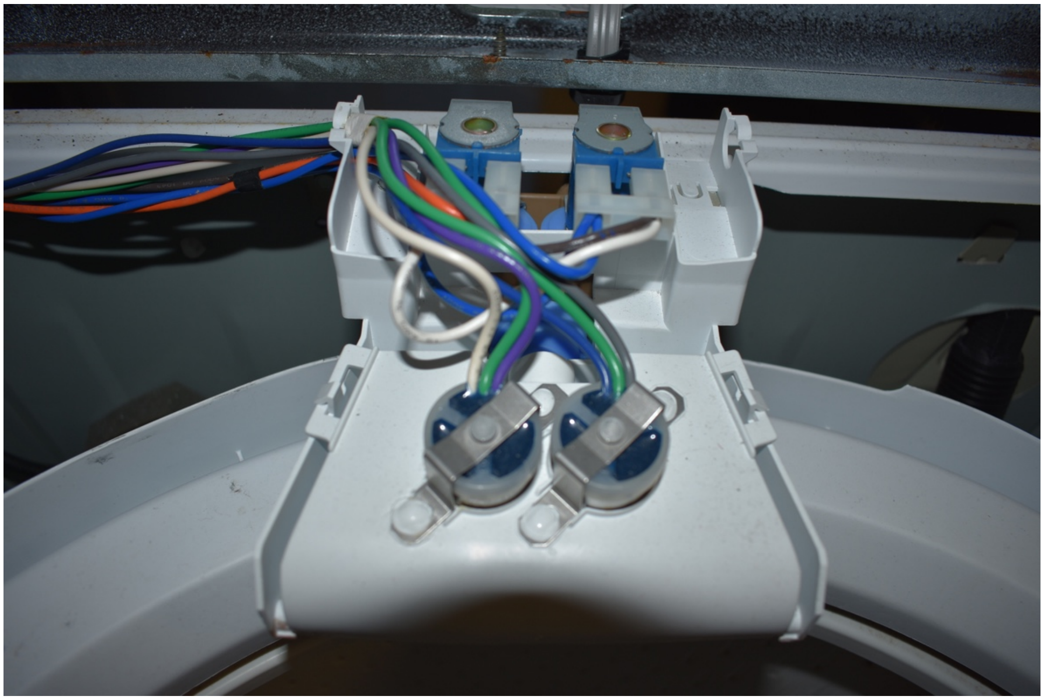


Photo #58 – The inlet valves. The devices to the bottom of the photo are thermostats.

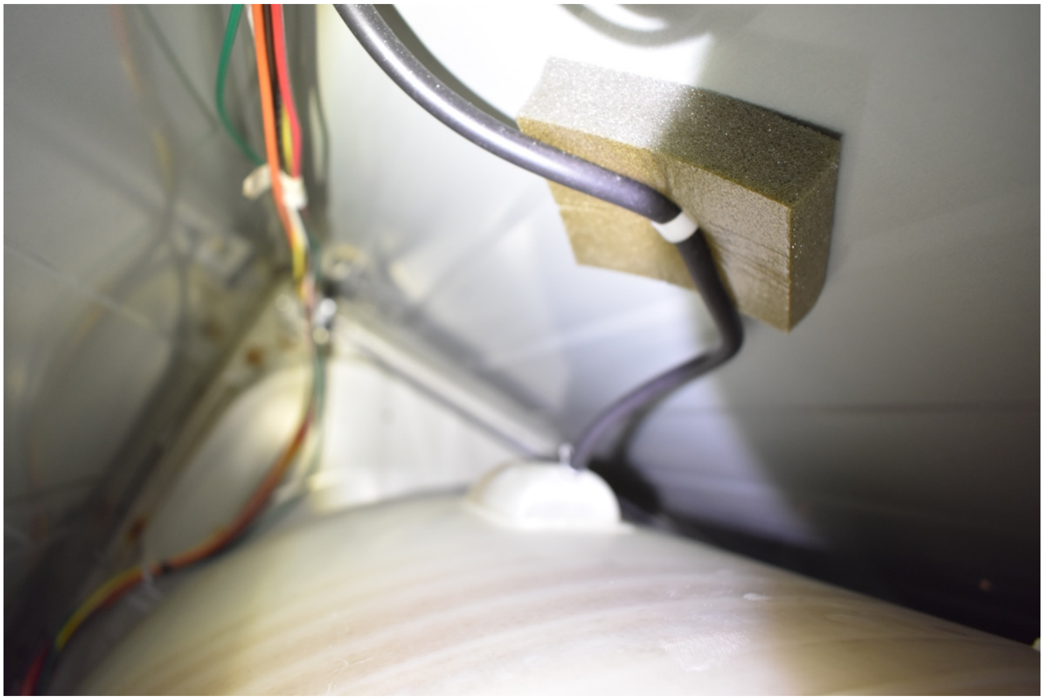


Photo #59 – The air tube and air dome.

Photo #60 – On the back of the console are three screws. Removing these…

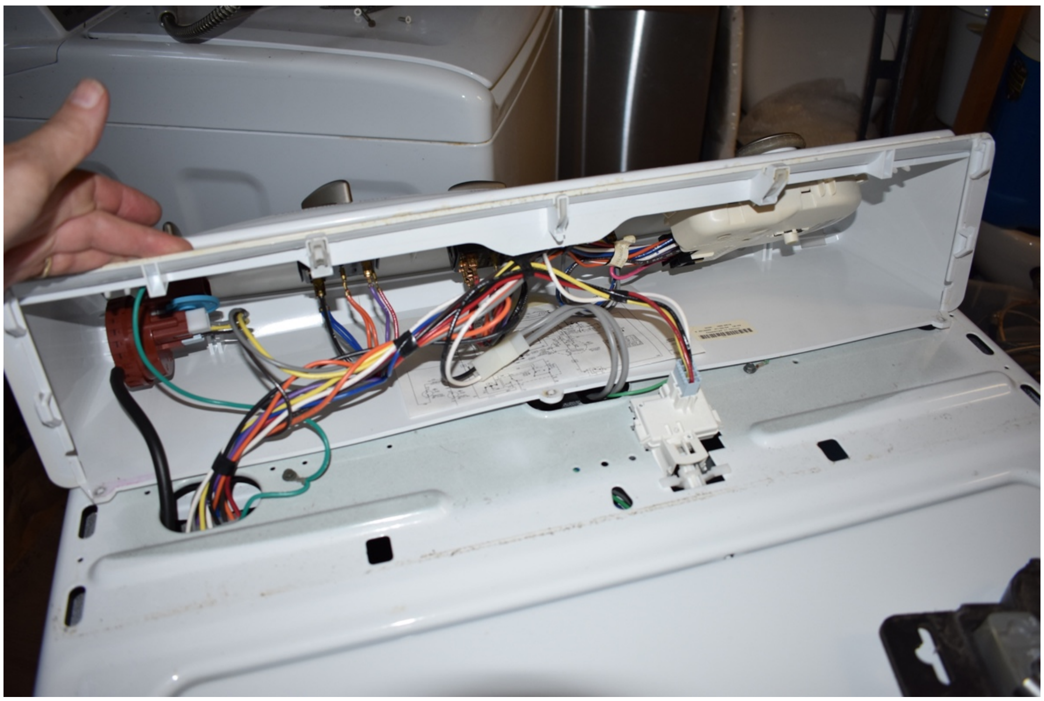


Photo #61 -- …allows the console to lift, exposing the controls.

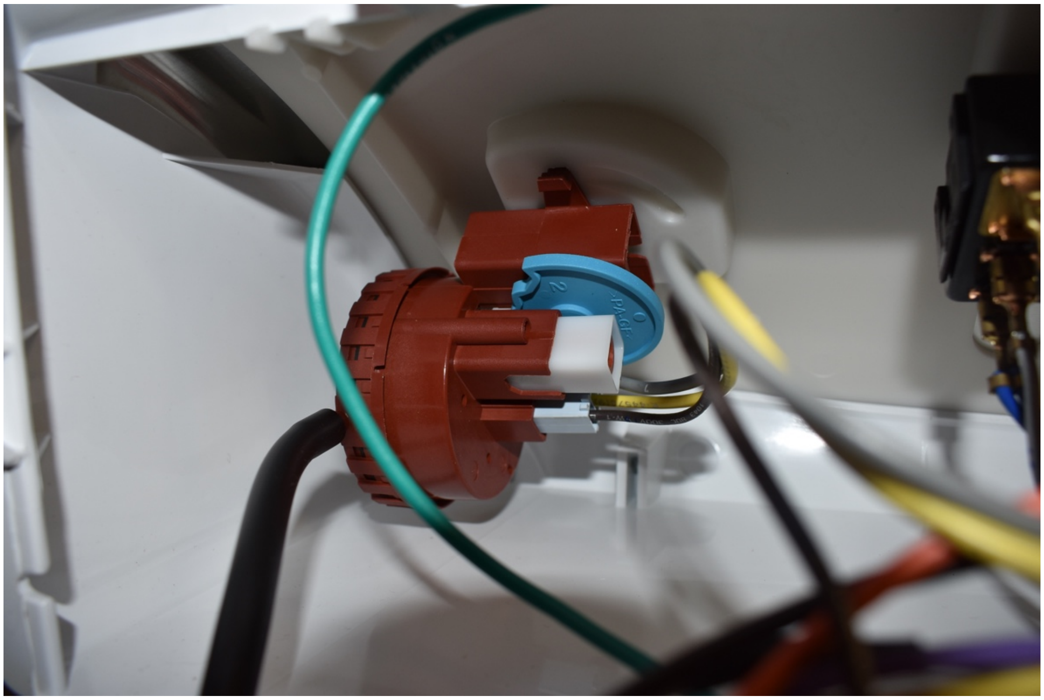


Photo #62 – This is the pressure sensor and water level sensor.

Photo #63 – This air tube is filled with debris and the rising air pressure as the tub fill can't be sensed by the pressure sensor in the console. Therefore, the inlet valve flow will not shut off and an overflow occurs.

Photo #64 – Another case of blockage of the air tube.

Photo #65 – The issue in this case was a supply hose installed by a rental company that had no washer in it. It leaked through no fault of the washing machine.

Photo #66 – This sump damage was found in a 4-month old washer.

Photo #67 – The installer put a zip tie on the discharge hose but it failed and the hose popped out of the standpipe.

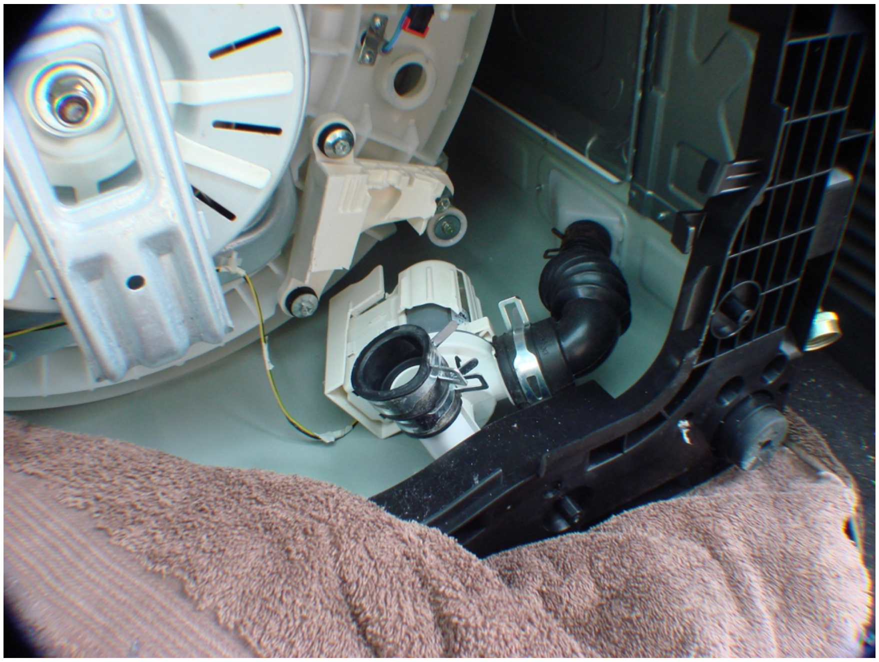


Photo #68 – This is a fractured pump bracket. The manufacturer attached the pump assembly to the tub, which vibrates in use. I have seen 4 cases of this same failure. The fix was to move the pump assembly to be supported on the frame of the machine. At failure, the pump assembly pulled the large hose connection off of the tub. The open nozzle is above at the top center of the photo.

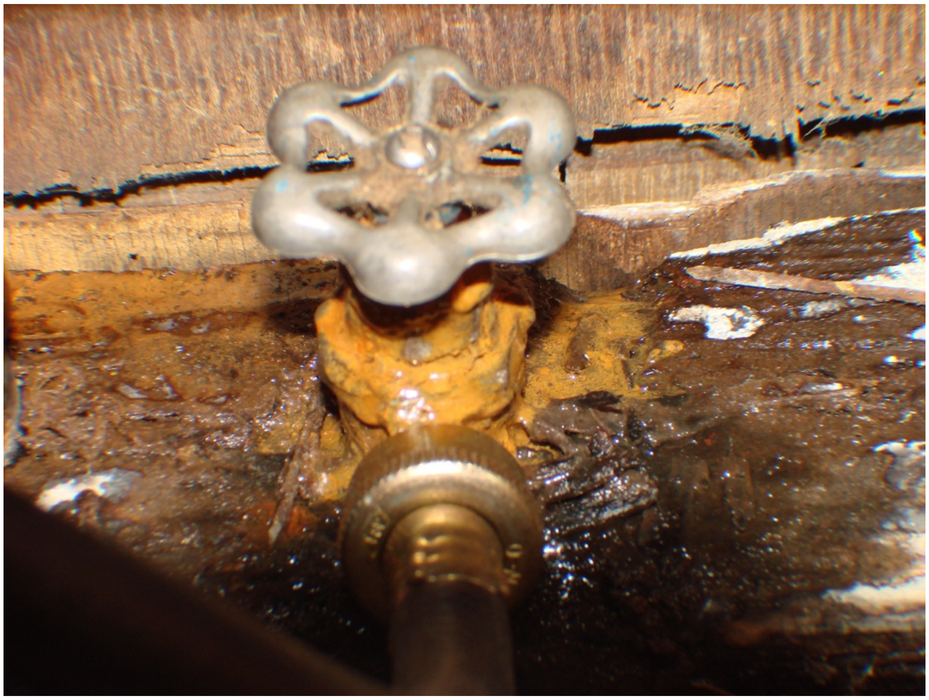


Photo #69 – The machine was not at fault for a long-ignored faucet leak.

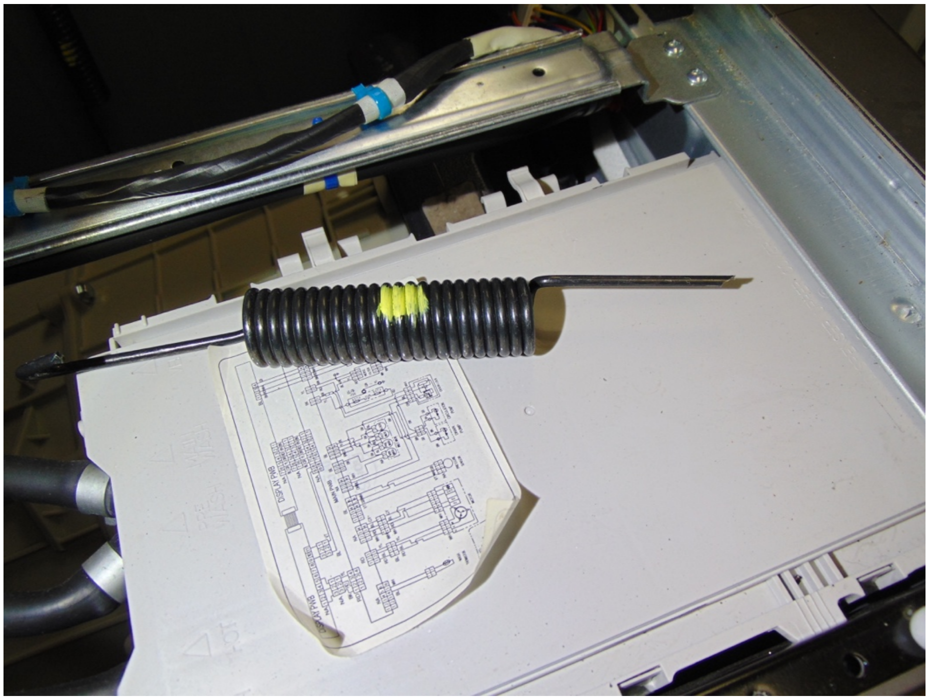


Photo #70 – This is the machine shown in Photo 50. One may have noticed that one of the two drum support springs was missing. It had failed in service.

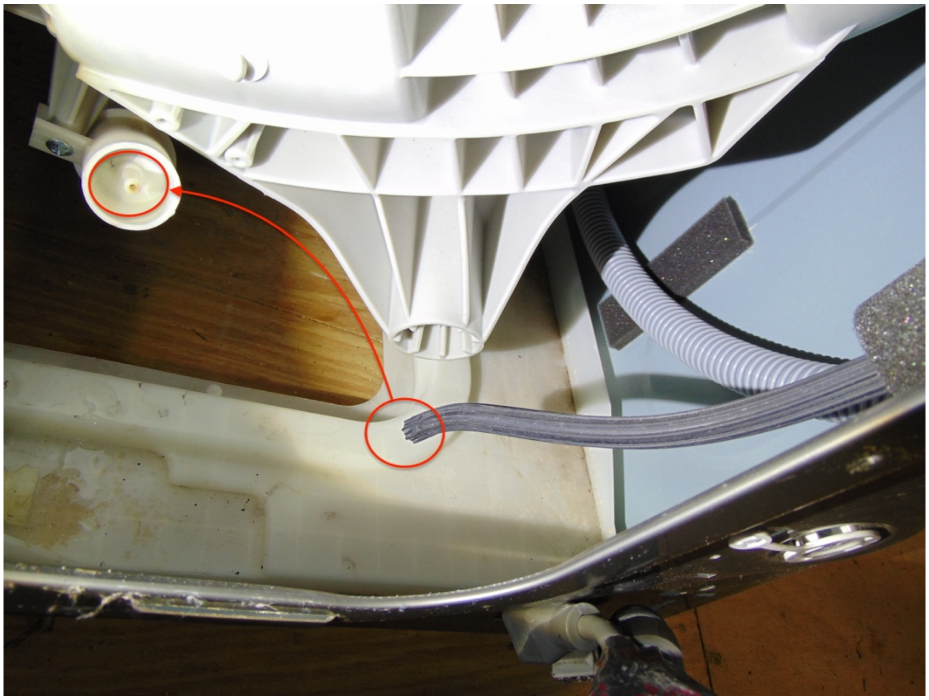
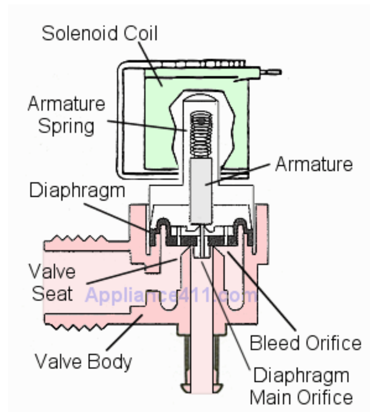


Photo #71 – When it failed, it pulled the pressure sensor air tube off the drum and caused a leak.

ATTACHMENT A

Appliance Water Fill Valve Operation

Appliance Water Fill Valve Operation



The valve body provides an incoming water supply connection and a main passageway with a large orifice and seat where the water flow can be stopped. The outlet of the valve connects to the water system of the appliance or if part of a clothes washer 'mixing valve', empties into a hot/cold water mixing chamber before exiting the valve. In the case of a mixing valve, each solenoid has a separate valve system which is similar in construction and operation to the other.

A rubber diaphragm operated by water pressure against the valve seat is used to start and stop the flow of water through the valve. The diaphragm has several small bleed orifices outside the seat contact area and the main diaphragm orifice in its center. The armature of the valve serves to open the main diaphragm orifice as the solenoid is powered. A coiled spring holds the armature down against the main diaphragm orifice closing its aperture when the solenoid is not energized. The armature itself operates within a closed metal tube called the valve guide.

The following explains the basic valve operation:

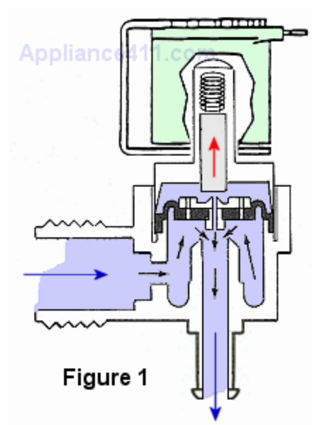


Figure 1

When the valve is in the closed position (figure 2) with its solenoid coil not energized, water migrates through the diaphragm's bleed orifices allowing incoming water pressure to build up on top of the valve diaphragm. The bottom of the diaphragm being open to the valve outlet is essentially at atmospheric pressure. This pressure differential holds the valve shut.

When the solenoid is energized (figure 1), the resulting magnetic field pulls the armature up into the valve guide compressing the armature spring. When the armature moves up off the diaphragm it allows the water that has built up on the top side of the diaphragm to drain through the main center diaphragm orifice. The diaphragm's bleed orifices are much smaller than the main orifice so they will not allow enough water back through to maintain pressure on the top side of the diaphragm. As a result, the pressure on the top of the diaphragm is reduced causing the water pressure under the diaphragm to lift it off of the valve seat allowing a full flow of water through the main valve passageway.

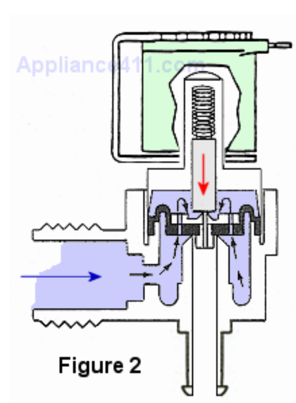


Figure 2

When the solenoid is de-energized (figure 2), the armature spring pushes the armature down closing the main diaphragm orifice. Water flows through the diaphragm's bleed orifices building up pressure above it until it equalizes on both sides of the diaphragm. The force of the armature and spring then pushes the diaphragm down against the valve seat to stop water flow through it.

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Appliance Water Fill Valve Operation

Constant GPM (gallons per minute) water valve

The water flow out of an appliance water valve is controlled by a rubber "flow washer" inside the valve body. This flow washer is designed to maintain a constant flow rate through the valve provided an incoming water pressure of between 20-30 PSI to 120 PSI is supplied to the valve.

Testing

Using an ohmmeter the resistance of the solenoid coil(s) can be tested to see if they are defective or not. They should measure between 200 and 900 ohms depending on the coil's wattage. If the coil tests as having infinite resistance, it is defective.

To simulate normal valve operation on a 120 volt rated valve, each solenoid coil may be directly connected to a separate 120 volt power supply using a property fused and grounded service test cord.

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ATTACHMENT B

Water Pressure Reducing Valve Operation

Zurn Wilkins PRVs

With over 100 years of trusted performance, Zurn Wilkins PRVs offer durability and proven reliability. The Zurn Wilkins PRV saves the average home between 30,000 and 40,000 gallons of water by reducing pressure from 100 psi to 50 psi.

How PRVs Operate

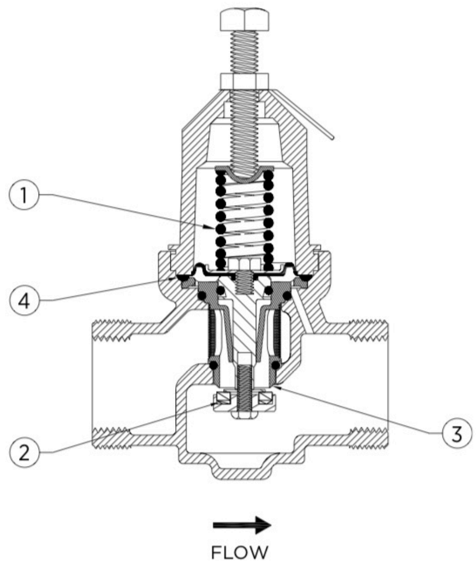
Zurn Wilkins direct-acting pressure reducing valves are normally open and are biased to the open position by a preloaded spring (1).

The valve will remain in the open position until downstream pressure forces the plunger (2) onto the seat (3), closing the valve. The valve is closed by reduced pressure water pushing on the wetted side of the diaphragm (4), countering the force of the spring (1). The amount of reduced pressure is directly proportional to the preloaded spring (1).

When the valve is pressurized, it remains closed until downstream demand is placed on the system. When demand occurs, such as turning on a faucet, the outlet pressure drops and decreases the force on the wetted side of the diaphragm (4), allowing the spring (1) to bias the valve open to satisfy demand.

The valve will continue to modulate in the open position until the demand placed on the system ceases.

When demand ceases, the valve will close. Pressure reducing valves are capable of holding the static downstream pressure within very narrow limits, because the operating intelligence for PRVs is independent of inlet pressure, regardless of inlet pressure fluctuations.



Integral Bypass

The pressure downstream of a PRV can build from thermal expansion or the use of pumps. When downstream pressure builds and exceeds inlet pressure, an integral bypass bleeds off excess pressure by allowing water to flow upstream through the bypass, limiting pressure build in a system to that of the inlet pressure.

With an integral bypass, pressure in a system will never exceed that of the inlet pressure if there is no backflow prevention device installed.

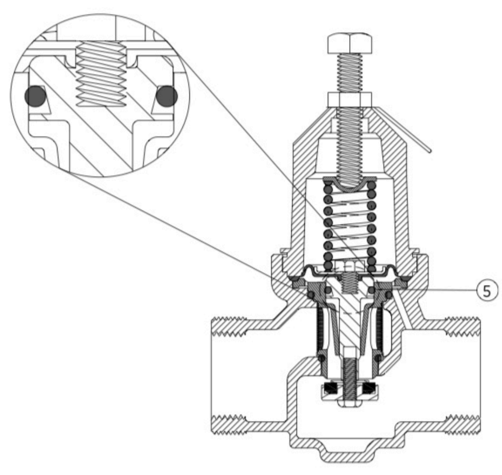
Excess downstream pressure can cause a temperature and pressure relief valve (T&P valve) installed on the hot water heater to open when system pressure exceeds the T&P valve set point (typically 150 psi). T&P valves are safety devices designed to operate a limited number of times in emergency situations only. An integral bypass will keep pressure from rising to the T&P opening point if inlet pressure is less than 150 psi.

All Zurn Wilkins PRVs have integral bypasses that operate by using an O-ring in a conic O-ring gland (5).

Under normal conditions, where water pressure coming into the PRV is greater than the downstream pressure, the O-ring is pushed into the narrow section of the gland by incoming pressure and seals tight.

In the event that the pressure on the downstream side of the regulator becomes equal to the incoming pressure, the O-ring will slide to the wide section of the gland to unseal, opening the bypass.

If a backflow preventer is present, or if inlet pressure is excessive, a pressure relief valve or thermal expansion tank (Zurn Wilkins XT series) should be installed downstream of the PRV to address thermal expansion.



NR3XL with Integral Bypass

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