Anticipatory Failure Determination

Gas Compressor Problem

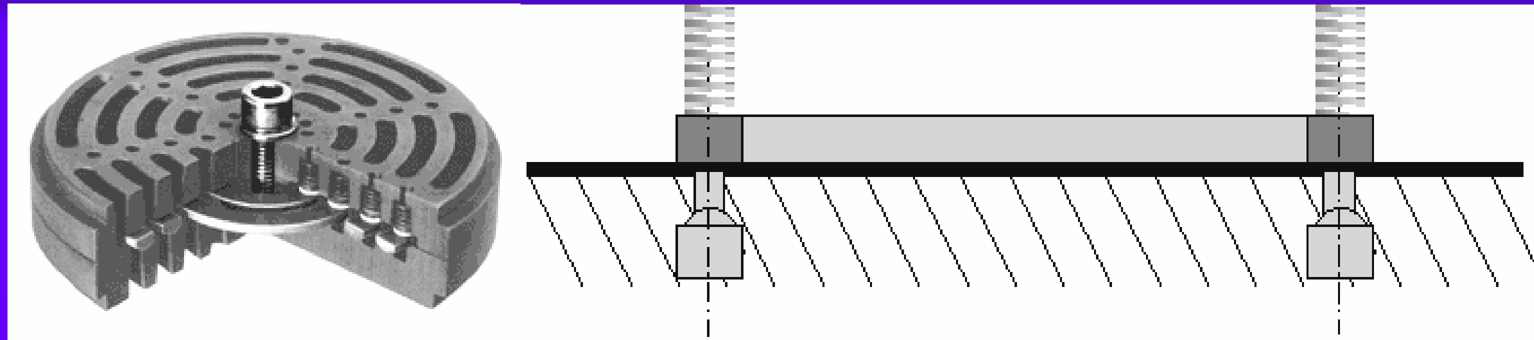
Premature Valve Failure

The Ideation Process for Failure Analysis

1. Failure Analysis Questionnaire

- There is a system called **compressor** for **increasing the gas pressure used for a reaction**.
- Gas is supplied to compressor from two units (one unit supplies clean synthesized gas, another supplies gas reformed after the production process).
- An undesired effect, **premature valve failure** (broken valve plates, cracks of valve plates, wear on the plates, weak springs, seat worn etc.) occurs in the process of compressor operation.

- Let's fire up the AFD software. The white screen on the left shows the *Ideation Process for Failure Analysis*, where the problem has been documented. (This problem resulted in $250,000 in operational losses and maintenance costs per year.) On the right we will enter some remarks that were not incorporated into the original report about the resolved problem.



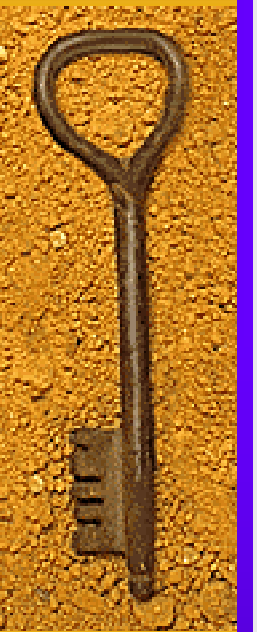
- This is this famous compressor valve. To keep it simple, we can say it consist of:
  - Seat (bottom parts with openings into the cylinder)
  - Plates (the rings that open and seal the cylinder 600 times per minute).
  - Springs (the stuff that forces the rings to close the valve)

- **1.1. Failure or drawback for which the root causes are unknown**

  An undesired effect **premature valve failure** (broken valve plates, cracks in valve plates, plate wear, weak springs, seat worn, etc.) occurs under the conditions **operation of compressor**.

- The goal of the project was to reduce the losses and expense associated with premature valve failure twice.

- It was expected that after the reasons for the failure were revealed and eliminated, the life cycle of the valve would be extended by up to 3 years without a failure.



1.2. System where the failure occurs

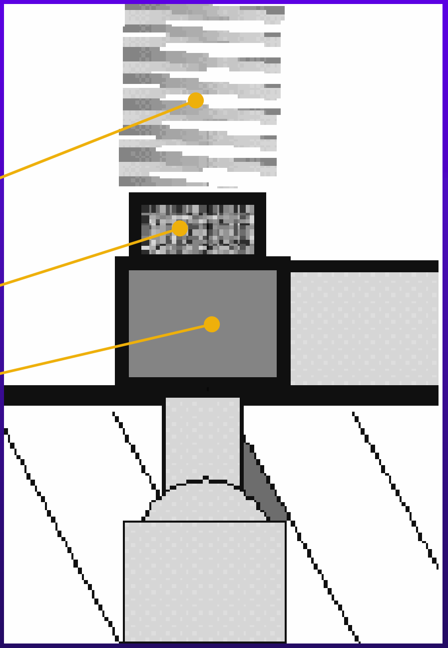
System name

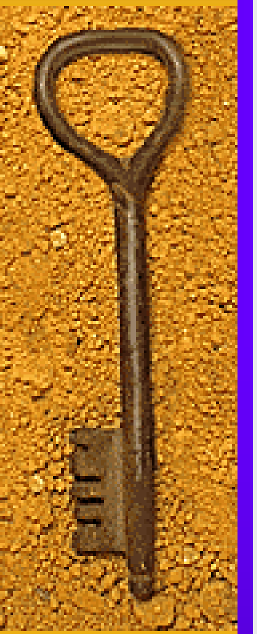
Compressor

System structure

- motor
- frame
- running gear
- cylinder
- piston
- carbon-Teflon rings and rider bands
- lubricating oil injection via the port into the cylinder
- suction valves:
  - seat
  - guard (top part of valve)
  - springs (steel)
  - button (plastic)
  - plates (plastic)
- discharge valves (see suction valves)

- It's easy to describe system structure, but it won't do much good until we create a list of the **useful functions performed by the system**.





Primary Useful Function

- The primary useful function of the compressor is increasing the pressure of the gas to be used for the reaction.

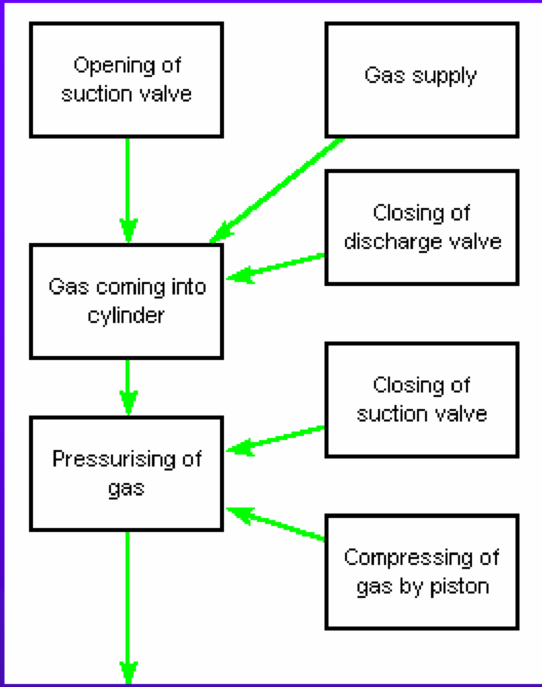
Useful functions

- opening of suction valve
- closing of suction valves
- compressing of gas by piston
- opening of discharge valve
- closing of discharge valve
- pressurizing of gas
- supply of pressurized gas to the next stage of the compressor

Harmful effects

- breaking of valve plates
- cracking of valve plates
- wearing on the plates
- weakening of springs
- wearing of the seats

- Using the AFD software we can build a functional model of our problem:



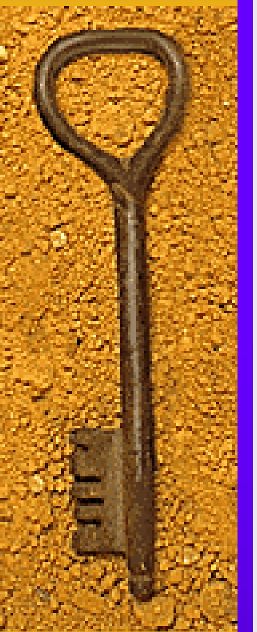
- This model reflects the functional links and the harmful effects induced by them.

- Once we describe the useful functions and harmful effects, we try to determine the **Last Event** – i.e., the event after which the failure appears.

2. Problem Formulation

2.1. Localizing the failure

- Gas is supplied to the compressor from two units (one supplies clean synthesized gas, the other supplies gas reformed after the production process).
- We do not have enough information to determine why the failure of the valves appears. We know, however, that the valve failures are observed as occurring more frequently on stages operating with gas from the second unit.
- After a flow analysis, the composition of the gas from the two units was compared. The presence of certain components (which can be liquefied) and impurities in the gas from the second unit was reported.
- Subject Matter Experts had assumed that the valve failures were linked to the appearance of a liquid (liquid hydrocarbons) in the compressor and the ensuing penetration of this liquid into the discharge valves. They were able to detect the time when the valve leakage started, but could not take the compressor out of operation and stop the production process.



Last Event

- Falling droplets of liquid from the gas after compression

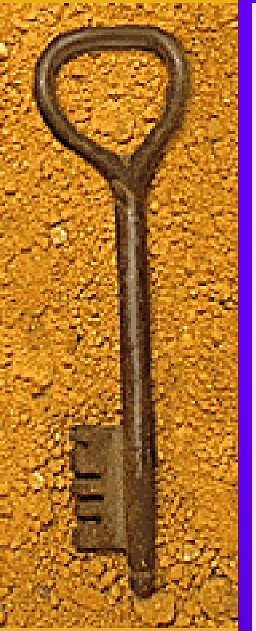
Conditions that initiate or accompany the failure

- Presence of heavy hydro-carbons in the gas
- Pressurization of gas
- Presence of impurities in the gas

2.2. Formulating the Inverted Problem

1. Find a way to provide [the] (Breaking of the valve plates) with help of [the] (Opening discharge valve) and (Closing of discharge valve), and any other function, which happens before the Last Event.
2. Find a way to provide [the] (Cracking of valve plates) with help of …..

- Okay, we've created the Failure Diagram. Now hit the button and the software will formulate "problem statements" for you!
- There's plenty of room for creativity when solving the problems generated by the AFD software! Here you see one of the inverted problems. Why do we need them? We select one, then amplify it and generate Failure Hypotheses. Check out the next pages!



3. Providing Failure Hypotheses

3.1. Amplifying the Inverted Problem

- It is necessary to produce *crush all valve plates, springs, wearing all seats* under the given conditions *existing operational process*.

3.2. Generating Failure Hypotheses

Hypotheses:

Hypothesis #1:

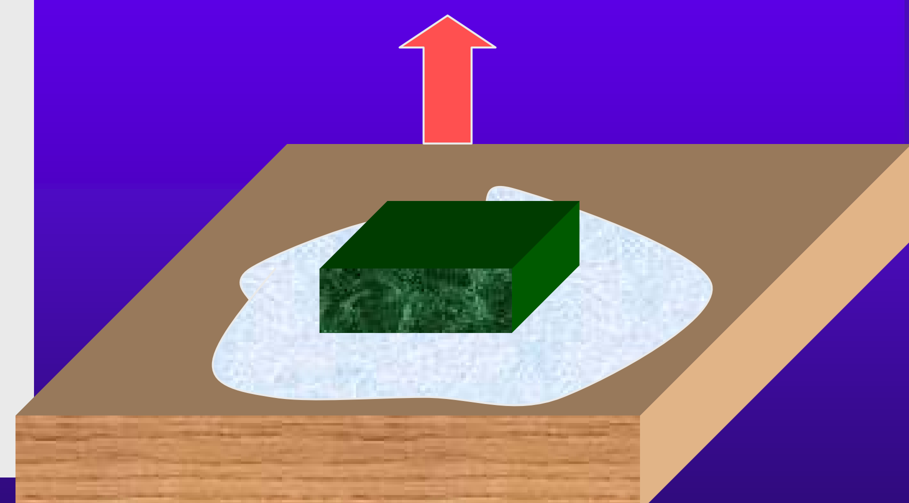
- During the process, metal parts can be charged negatively and the plastic parts positively.
- Hydrogen radicals, ion-radicals, or ions obtained in process from gas from the second unit accumulates on the surface of the metal details.
- Accumulated hydrogen penetrates into the inner parts of the metal details in the presence of temperature gradients.
- Possible sources of radicals, ion-radicals, or ions is the gas produced by the 2nd unit.

Hypothesis #2:

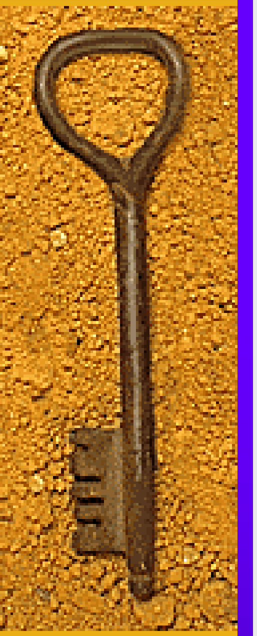
- After liquid droplets fall from the gas they contact the surface of the valve-plate, moistening it. The valve begins to open but the wetted area of the plate adheres to the contact surface and hinders it from opening.
- The moment the valve first opens is delayed, irregular and will be misaligned, because the contact surface is partially wetted. The plate will be under substantial bending forces, which can be a cause of destruction in the case of multiple recurrences.

(continued)

- We can easily check this hypothesis with a simple experiment:
  - Make the surface of the table very wet
  - Put a flat plastic or metal part on it
  - Try to quickly lift the part

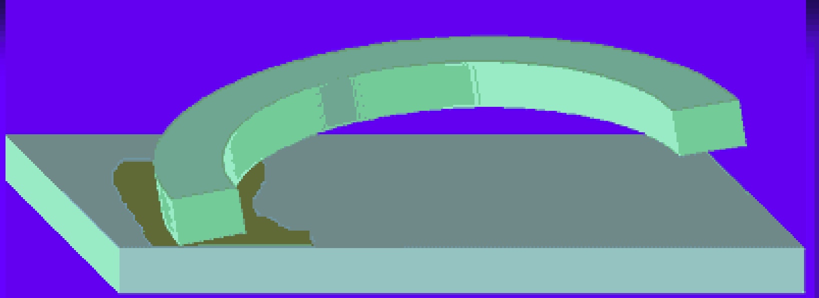


The resulting adhesion means that significant additional effort is required to break away the part from the table.

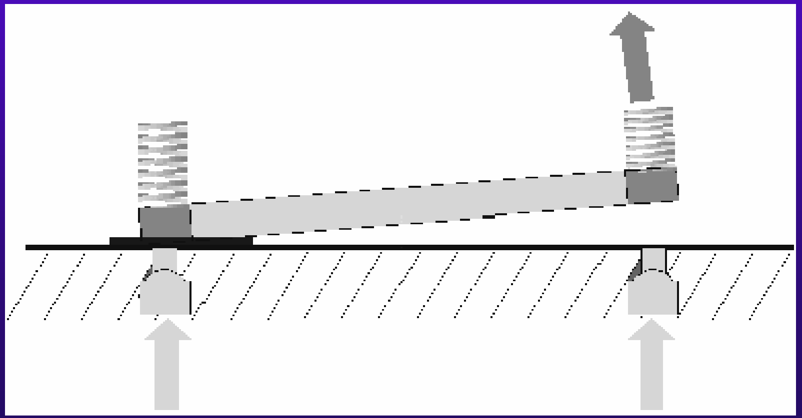


Hypothesis #2

- After liquid droplets fall from the gas they contact the surface of the valve-plate, moistening it. The valve begins to open but the wetted area of the plate adheres to the contact surface and hinders it from opening.
- The moment the valve first opens is delayed, irregular and will be misaligned, because the contact surface is partially wetted. The plate will be under substantial bending forces, which can be a cause of destruction in the case of multiple recurrences.
- In the next moment the plate sticks to the wetted surface and quickly moves back with a speed higher than the speed of the opposite side of the plate. This can cause the opposite side of the plate to become misaligned.



- If we want to crush something, we must have destructive forces. These forces must be present as RESOURCES. Most powerful resource we have is gas pressure, which can lift the plate and open the valve. To crush the plate we must affix it at one side and prevent regular opening.



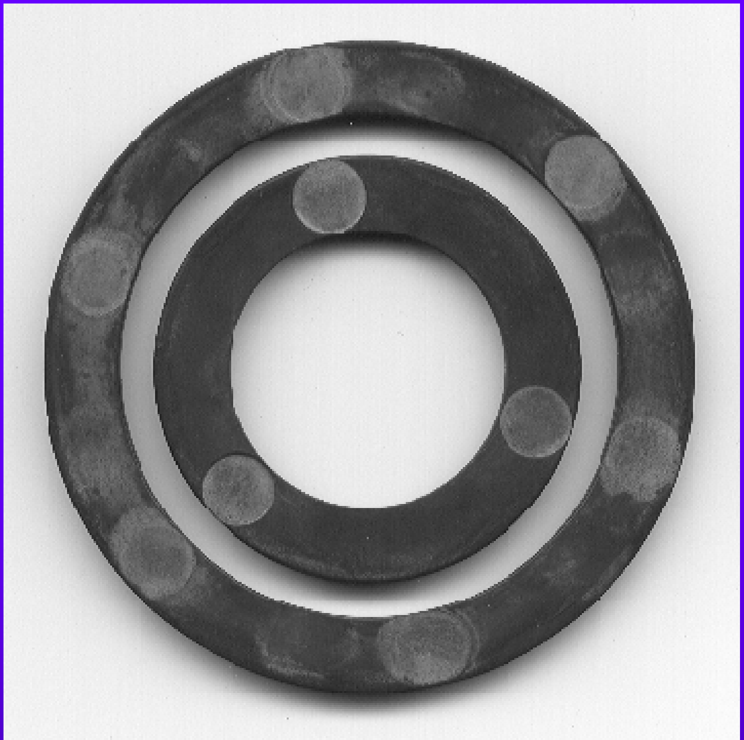
Hypothesis #2

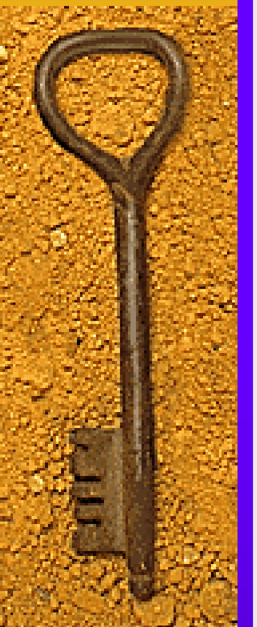
- Oscillations of the plate will produce a number of undesired effects
  - Additional bending forces, accelerated destruction of the plate.
  - Multiple oscillations load the springs and they compress more than anticipated. This reduces the lifetime and flexibility of the springs.
- Simultaneous action of high vibration of the compressor and adhesion causes:
  - Acceleration of the spring fatigue process.
  - Opening of different plates at different times.
  - Accelerated wearing of the bottom part of the plates.
  - Accelerated wearing of the top parts of the plates.

- The springs have been weakened and break prematurely. They should operate for years, but can only operate for months. How can we exhaust the design limits of the working cycles? How can we make the springs pass all design cycles in one month? Clearly, this can only be achieved by compressing the spring not once, but at least 5-10 times during each working cycle. This is possible only if there are oscillations present in the system. Our new task: ***How can we create these oscillations?***

Hypothesis #2

- Weak springs and oscillating movement of the plate cause:
  - Loosening of buttons
  - Penetration of buttons into the space between the plate and walls as they move.
  - Ensuing destruction of the plates.
- In the case of complete wetting of the contact surface, the failures will be similar to those in the case of partial wetting: late opening of the valve with one part opening first, then another; misalignment; increase in plate oscillation.





3.3. Verifying Failure Hypotheses

- Hypothesis #1 was rejected after the gas composition analyses, due to the absence of a sufficient amount of active radicals, ion-radicals, or ions.

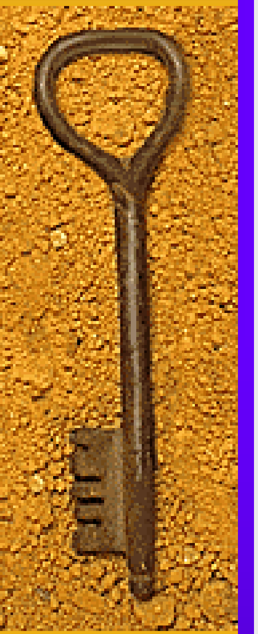
Verified Hypotheses:

- Hypothesis #2 was approved because of the presence of all components and required conditions during operation.

- After a thorough consideration of the available resources, one possible failure was added:
- Presence of gas in the liquid can cause cavitations. This effect can cause erosion of contact surfaces.

- Some people liked the hypotheses and others didn't. This is why the following article in the January 1996 issue of *Hydrocarbon Processing* greatly helped in verifying Hypothesis #2:

> Based on the surveys it has become very evident that the old phrase "it is better to have too much cylinder lubrication rather than too little" *is a serious and widely applied misconception.* Excessive cylinder lubrication can be just as, and in some cases even more, detrimental to reliability than having insufficient cylinder lubrication. Too much of the wrong type of lubricant can increase the effects of compressor valve sticktion (viscous adhesion) causing compressor valves to open and close late. This results in the valve elements "slamming" open and shut, significantly reducing reliability.



4. Preventing or Eliminating Failures

- The ideal way to prevent the failures is to eliminate condensation of the liquid. This can be achieved by elimination of the liquid or heating.

4.1. Prevention Problem Formulation

4.2. Prevention Concept Development

Concepts:

- It is reasonable to assume that condensation appears because the metal parts cooled by the outside air are colder than the gas flow. The valve must be warm enough in order to avoid the harmful effect of condensation. Increasing the temperature of these parts can be achieved by:
  - Covering the valves with a layer of thermal insulation
  - Additional heating of the valve area using existing thermal resources

  Even in the presence of liquid, the life of the parts can be increased by:
  - Reducing oscillation of the valve plates
  - Modifying the plate design to reduce lift-off forces
  - Applying a more efficient material for the plates