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Root Cause Analysis of Water Wastage in Hot - Cold Water Dispenser

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ABSTRACT
Hot - Cold Water Dispenser is a high end kitchen product mounted on sink of kitchen to meet the requirement of instant hot and cold water as desired. It provides cold water at ambient temperature and hot water at near boiling temperature of about 97ºC to meet the instant water need. It was reported from few users, small amount of unnecessary water get dispensed from the Hot - Cold Water Dispenser during the idle conditions. This is undesirable and affecting on the overall performance of product.
This paper briefs the available Root Cause Analysis and process to select the suitable method to find out the root cause of problem. From the available methods, Fault Tree Analysis was found to be most suitable method. The paper describes this method in length. Fault Tree Analysis is used as the scientific approach to find the root cause of problem of water dripping in Hot - Cold Water Dispenser at idle condition. It makes use of a graphical representation of the major faults associated with the product, the causes for the faults, and potential countermeasures. It is found that the FTA tool helps to identify areas of concern for new product design as well as for improvement of existing products.
Keywords **-** Aspirator, Dispenser, Expansion Tank, Faucet, FTA, Hot Water Tank, RCA, Safety.

I. INTRODUCTION

Hot Water Dispensers are classified as Hot Water Dispenser & Hot - Cold Water Dispenser. Hot Water Dispenser provides hot water instantly to meet the user requirements where as Hot - Cold Water Dispenser provides hot as well as cold water. From product assembly perspective, there is a small difference between the Hot - Cold & Hot Water Dispenser. Check Valve is used only in the Hot - Cold Water Dispenser.

Figure 1 shows general parts assembly. One end of 3/8" flexible plastic tube is connected to main kitchen water supply point with brass nut and insert. Other end of the same tube is connected to water filter inlet port by quick push connector. Output port of water filter is connected with similar flexible plastic tube, whose other end has quick push connector and connected to inlet of faucet by flexible copper tube. In the valve body of faucet, inlet of faucet is divided in three water lines as inlet of Hot Water Tank, outlet of Hot Water Tank & main faucet discharge line which are operated by 3/2 direction control valve.

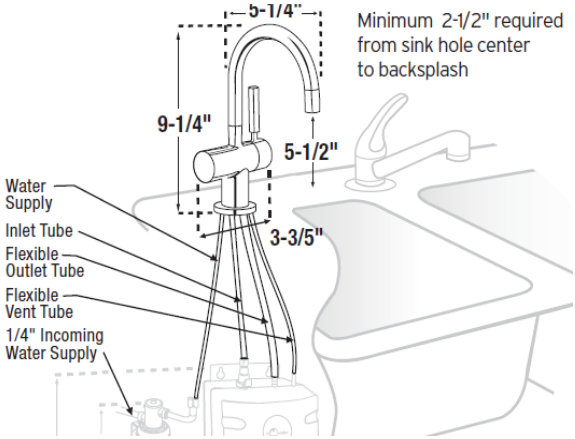


Figure 1 Hot - Cold Water Dispenser

A copper tube followed by 1/4" polyethylene tube from faucet is connected to inlet port of hot water tank via aspirator unit. Aspirator unit has two outlets one goes to hot water tank and another goes to expansion tank. Output of expansion tank is connected to faucet by 5/16" plastic tube followed by copper tube. Outlet of hot water tank is connected to faucet via 7/16" silicone tube followed by copper tube. In between check valve is provided for preventing cold water flow into hot water tank when faucet is operated for cold water output.

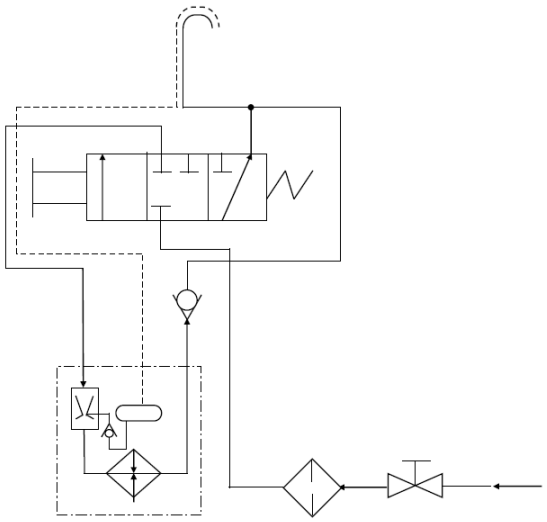


Figure 2 Hot - Cold Water Dispensers

Figure 2 shows hydraulic circuit diagram of Hot - Cold Water Dispenser which is operated by 3/2 direction control valve. To get the hot water from faucet, handle lever need to be pushed downwards & rotated clockwise. By doing so cold water from water filter comes into the faucet via flexible copper tube & goes to hot water tank via copper tube followed by polyethylene tube. Hot water available inside hot water tank comes in outlet tube and flows to faucet after lifting the check valve.

To get cold water from faucet, user needs to press the lever & rotate handle in anticlockwise direction. By doing so, cold water from water filter flows to faucet and gets dispensed without going cold water inside the hot water tank. In this condition, check valve prevent cold water to enter into hot water tank.

Electric & water supply are always ON with auto shut OFF mechanism provided for electricity. It means electric supply always remains ON for the desired water temperature even in the idle condition when user does not operate the dispenser.

II. DETAILS OF SCOPE

Hot - Cold water dispenser is made up of different subcomponent or systems such as water filter, hot water tank, expansion tank, check valve, aspirator, faucet, valve & tubing.

During the Idle condition, when electricity is ON, and there is no water discharge from unit, water gets expanded continuously and tries to catch the empty space. However there is no empty space inside the system until operates the unit. So, expanded water gets dispensed. This phenomenon is called as Water Dripping. There are lot many different parameters responsible for water dripping which needs to be identified to work upon for performance improvement. Using suitable & appropriate root cause analysis method, one can reach to the root cause of water dripping.

III. ROOT CAUSE ANALYSIS (RCA)

Root Cause Analysis (RCA) is a method of problem solving that tries to identify the root causes of faults or problems. A root cause is a cause that once removed from the problem fault sequence, prevents the final undesirable event from recurring. Generally the purpose of root cause analysis is to find out effective solution to the problems such that they do not recur. Now days there have number of RCA tools or methods available. It depends on the designer to select most suitable method based on certain application.

Few of the RCA tools / methods are:

- Event & Casual Factor Charting
- Change Analysis
- Barrier Analysis
- Tree Diagram
- Why-Why Chart
- Pareto Analysis
- Storytelling Method
- Fault Tree Analysis
- Failure Mode & Effect Analysis
- Reality Charting

The work described in this paper is the process to select most appropriate method suitable for Hot - Cold Water Dispenser to find out root cause of water dripping.

Using the systematic comparison among all root cause analysis tools, appropriate method can be selected. However the tool suggested by comparison may not be the best solution for given typical application unless it is checked on engineering skill and logics for particular operational issue.

Table 1 Comparison of RCA Methods

Method/Tool	Type	Define Problem	Define all casual relationship	Provides a casual to root causes	Delineates evidence	Explain how solutions prevent recurrence	Easy to follow report	Score
Event & Casual Factor Charting	Method	Yes	Limited	No	No	No	No	1.5
Change Analysis	Tool	Yes	No	No	No	No	No	1
Barrier Analysis	Tool	Yes	No	No	No	No	No	1
Tree Diagram	Method	Yes	No	No	No	No	No	1
Why-Why Chart	Method	Yes	No	Yes	No	No	No	2
Pareto Analysis	Tool	Yes	No	No	No	No	No	1
Storytelling Method	Method	Limited	No	No	No	No	No	0.5
Fault Tree Analysis	Method	Yes	Yes	Yes	No	Yes	No	4
Failure Mode & Effect Analysis	Tool	Yes	No	Limited	No	Limited	No	2
Reality Charting	Method	Yes	Yes	Yes	Yes	Yes	Yes	6

Using the above comparison table, it is seen that Reality Charting is best RCA tool among all the above mentioned selected methods. However it is difficult for Reality Charting to find out the root cause of water dispenser system. Now as fault tree analysis has second highest score, it seems to be suitable and appropriate method for finding the root cause of water dripping in water dispenser system. It

is also established that the fault tree analysis is more effective for complex system.

IV. FAULT TREE ANALYSIS (FTA)

Fault tree analysis is a graphical representation of the major faults or critical failures associated with a product, the causes for the faults, and potential countermeasures. The tool helps in identifying areas of concern for new product design or for improvement of existing products. It also helps to identify corrective actions to correct or mitigate the problems.

Fault tree analysis is useful both in designing new products and in dealing with identified problems in existing products. As a part of process improvement, FTA is used to identify root causes of problem and also used to design remedies and countermeasures for rectifications.

The typical methodology of FTA is that each event is analyzed by asking, "How could this happen?" In answering this question, the 'primary causes' and 'how they interact to produce an undesired event' are identified. This logic process continues until all potential causes have been identified.

Throughout this process, a tree diagram is used to record the events as they are identified. Tree branches ceases to grow further when all events leading to the negative event are complete. Symbols are used to represent various events and to describe the relationships between events.

V. METHODOLOGY

While working with FTA for any system, it is very much expected that the designer has sufficient product knowledge so that he/she will be able to know the function of each component of the system. In the absence of in-depth product knowledge, designer will not get the accuracy of results. In short accuracy of Fault Tree Analysis is totally depending upon the designer's product knowledge and designer's skill to apply FTA to identify the root cause of failure.

Below are the essential step arranged in sequential manner to perform the FTA on any product to identify the root cause of failure.

1. Select a component for analysis. Draw a box at the top of the diagram and list the component inside.
2. Identify critical failures or "faults" related to the component. Using Failure Mode and Effect Analysis (FMEA) is a good way to identify faults during quality planning.
3. Identify causes for each fault. List all applicable causes for faults in ovals below the fault. Connect the ovals to the appropriate fault box.
4. Work toward a root cause. Continue identifying causes for each fault until root cause or controllable causes are identified.
5. Identify countermeasures for each root cause. Using brainstorming or a modified version of force field analysis are best tools to develop actions to counteract the root cause of each critical failure. Create boxes for each countermeasure, draw boxes below appropriate root cause, and link them.

VI. FTA WITH WATER DISPENSER

Our area of interest here is to identify the root causes of water wastage; hence problem statement is to find out the root causes of water dripping.

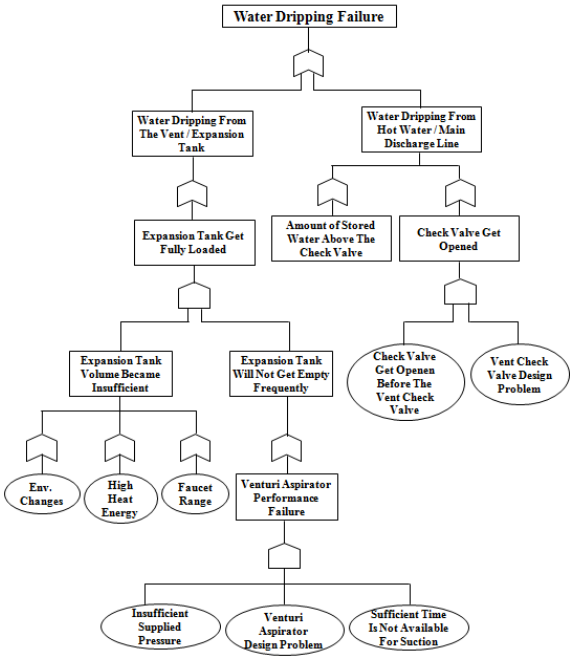


Figure 3 FTA for Water Dripping Failure

VII. FTA RESULTS

As per the Fault Tree Analysis conducted on Hot - Cold Water Dispenser for finding the root cause of water wastage by water dripping. Analysis shows four probable root cause of water dripping, those are:

Expansion Tank: Expansion Tank is the sub system or component of Hot - Cold Water Dispenser and is used to store expanded water as well as release the same water to Hot Water Tank through Venturi Aspirator. From the FTA, it seems that available volume of Expansion Tank is insufficient to store the expanded water.

Venturi Aspirator: Role of venturi aspirator is to allow or relief expanded water to expansion Tank when user don't want hot water & return expanded water back to Hot Water Tank while Faucet operated for hot water application. This is done by venturi effect by creating negative or suction pressure in the aspirator & works as pump to suck the expanded

water from expansion tank. From FTA, it seems that the required suction pressure is not getting created inside the venturi aspirator.

Amount of water stored above main check valve: Check Valve is provided in hot water line in the Hot - Cold Water Dispenser. Role of this Check Valve is to allow hot water flow to Faucet when operated for hot water application & restrict the flow of cold water into the tank when operated for cold water. There is about 12.5" of water column always present above the check valve, which gets converted into water dripping.

Check Valves: It happens that for the some period of time check valve does not perform its operation for which it is designed.

VIII. RESULT VALIDATION

Based on the FTA result the basic or probable root causes of water dripping in Hot - Cold Water Dispenser are available. Next step is to validate these results by feasible methods to improve the product performance.

Through some basic calculations it is decided that for which system validation by prototypes needs to be carried out. Based on the calculations, it was observed that check valve performs its required function but rest of the three parameters mentioned as above needs to be validated by experimentation.

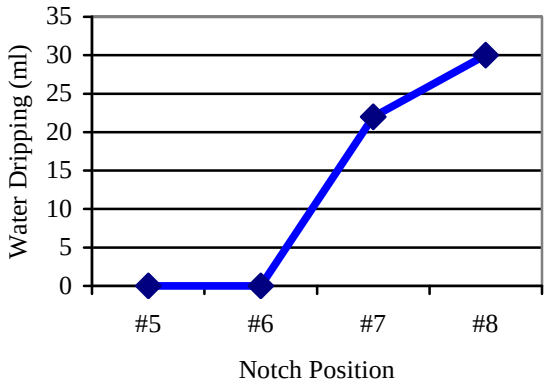
From the FTA results, new expansion tank was developed with increased volume. Venturi Aspirator was also redesigned to generate sufficient vacuum or suction or negative pressure. Similarly the main check valve position to be rearranged in such a way that that water column above check valve reduces. After the design, the prototypes were developed for testing.

To compare the improvement of water dripping in Hot - Cold Water Dispenser, existing unit was tested for water dripping with respect to various temperatures. Water dripping testing results were noted and plotted against temperature.

The typical graph is as shown in graph 1. The temperature control was achieved with setting the unit at predefined notch positions for uniformity in experiment.

Table 2 Existing water dripping test result

Notch Position	Water Dripping (ml)			
	(1)	(2)	(3)	Average
#5	0	0	0	0
#6	0	0	0	0
#7	20	24	22	22
#8	30	28	32	30



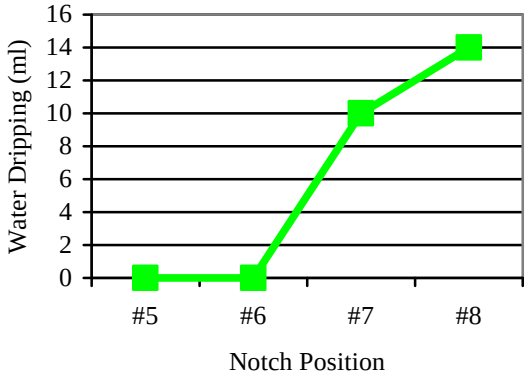
Graph 1 Existing design: Temperature Vs dripping

Testing results of water dripping dedicated that increase in the water temperature increases water dripping. From the results, the range of water wastage is around 0 to 30ml in Hot – Cold Water Dispenser.

As per FTA results, new concept were introduced and prototype for testing was developed to compare with existing results. This new design consists of modified expansion tank, modified venturi aspirator and changed position of check valve for reduced water column. This modified unit was again tested under similar conditions to check the water dripping with respect to various temperatures. Water dripping testing results were noted and plotted against temperature. Typical graph is shown in graph 2.

Table 3 New design dripping test results

Notch Position	Water Dripping (ml)			
	(1)	(2)	(3)	Average
#5	0	0	0	0
#6	0	0	0	0
#7	10	08	12	10
#8	12	16	14	14



Graph 2 New design: Temperature Vs dripping

Testing of prototypes with new design shows water dripping range from 0 to 14 ml in hot – cold water dispenser. This shows better performance than the existing one with 53% improvement.

IX. CONCLUSION

The problem identification was user feedback where water dripping was reported for hot – cold water dispenser. Based on this reported problem, the probable root causes of water dripping were identified based on the available Root Cause Analysis (RCA) tool or methods, the most suitable method for Hot - Cold Water Dispenser system was selected by comparing all RAC tools among each other. In this comparison, Reality Charting had the highest score but per logical study & past information suggested that rather than using reality charting tool, the next scored RCA tool i.e. Fault Tree Analysis needs to be used. Logical reason for choosing FTA was that it helps to identify corrective actions to correct or mitigate problems.

Hence based on this study, it was decided to use the FTA method to find out the probable root cause of water dripping & its solutions. The detailed Fault Tree Analysis (FTA) on Hot - Cold Water Dispenser was carried out to identify the probable root causes of water dripping phenomenon, FTA analysis showed four probable root causes of water dripping. FTA also gave an idea about why these components of the system were responsible for water dripping.

Based on FTA, modified design was suggested where all probable root causing components were validated for FTA results. New design was tested against existing design to compare water dripping. Prototype testing showed to great extent that results given by FTA were correct & proved that FTA is one of the acceptable methods to find out the root causes for such a complex system. Using Fault Tree Analysis method, performance improvement of 53% was achieved in tackling problem of water dripping.

REFERENCES

[1] Yongzhong TANG & Pingzhang GOU, *A Simple Case Study of FTA in Engineering, International Journal of Advanced Computer Science, Vol. 1, No. 2,* Aug. 2011, 84-86.

[2] Frank Ortmeier & Gerhard Schellhorn, *Formal Fault Tree Analysis - Practical Experiences, Electronic Notes in Theoretical Computer Science, 185* (2007), 139–151.

[3] Ashraf Labib & Martin Read, *Not just rearranging the deckchairs on the Titanic: Learning from failures through Risk and Reliability Analysis, Safety Science,* 51 (2013), 397–413.

[4] John C. Knight & Luís G. Nakano, *Software Test Techniques For System Fault-Tree Analysis, The 16th International Conference on Computer Safety, Reliability, and Security SAFECOMP,*1997.

[5] Clip Ericson, *Fault Tree Analysis - A History, 17th International System Safety Conference,* 1999.

[6] Frank Ortmeier & Gerhard Schellhorn, *Formal Fault Tree Analysis: Practical Experiences, AVoCS,* 2006.

[7] W. E. Vesely & others, *Fault Tree Book, U. S. Nuclear Regulatory Commission,* January 1981.

[8] Dean L. Gano, *Apollo Root Cause Analysis - A New Way of Thinking* (Third Edition, 2007).

[9] Manuals From InSinkErator.