Successfully Regained Lost Market through Application of FMEA Tool to Revamp Design of Single Phase Induction Motor

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Abstract

Kirloskar Electric Co was a leading supplier of Electrical Products in India around 1960s. It had about 28% to 30% Domestic Market share and had earned No. 1 position in the country. However, one of its products Single Phase Induction Motor got skidded in Domestic Market and had not earned a good name in the Export Market either. While the exact reasons for not being accepted in the Market were not known, the feeble voiced one single complaint did not lead to any particular clue. Hence, the Management assigned me the responsibility of identifying the problem and then evolving appropriate solution to overcome the issues involved. So, I went to Market in different cities in the country to identify the real issues and through use of FMEA tool (not a well known quality tool in 1960s in India) evolved both short term and long term solutions to counter the problems faced.

With this, the new design evolved for the product became the base solution to the problems that the customer had faced in both National and International Markets. The new design concepts used became the base for revamping the entire Series of Single Phase Induction Motor. New product was welcomed by both National and International Markets and there by original Market share was regained.

Keywords: Identification of Hidden issues, Use of FMEA tool to evolve solutions, Successful in winning customer trust, Redevelopment of full Series, Regained lost Markets - Domestic and International

1. Introduction

1.1 Introduction of Kirloskar Electric Organisation (around 1960s):

Kirloskar Electric (a family managed company) was established by Late, Laxmanrao Kirloskar - who established Kirloskar Group's First unit in 1925at Kirloskarwadi in Maharashtra State - at Bangalore in Karnataka State in 1946. Since then, it had grown up in size to Manufacture of Electric Motors in both 3 Phase with the range from 0.25 hp to 800 hp and Single Phase Motor with range 0.25 to 1 hp, Transformer – mainly Medium range Distribution type ranging up to 3000 KVA, Alternators (AC Generators) from 1 KVA to 1500KVA, DC Machines and DC Welding Generators, Geared Motors and Vary drive Motors. Its Marketing activities were through two organizations; a Sister company; Kirloskar Brothers Ltd. and also through an Associate company; Parry & Co Ltd. throughout India. Exports however, were fully managed by Kirloskar Electric only. It had attained a position of leading manufacturer of Electrical products in India by 1960s. Its turnover around 1963-1964 was of the order of INR 300 million. Exports were fetching about less than 5% share of total revenue.

Second Unit at Hubli (also in Karnataka State) was established in 1966 to Manufacture the smaller range of Electrical Machines. Initially, Manufacture of 3 Phase Induction Motors (of smaller range 1 to 10 hp) was established after moving out from Bangalore. Later, Single Phase Induction Motor range (of range 0.25 to 1 hp) was shifted to Hubli in 1970. Single Phase Alternator (of range from 0.5 to 5 KVA) followed above products in 1972.

In 1960s, Kirloskar Electric was managed by Chairman of Board of Directors Mr. NW Gurjar with Mr. Ravi Kirloskar as Chief Executive Officer. At the next level was Mr.SG Ramachandra - Chief Engineer and Mr. GN Paraki- Head of Rotating Machine Division- to whom I reported.

I joined this Oragnisation in July 1964, starting with an assignment in Rotating Machine Division's Induction Motor's Design and Development Group. Later, on being transferred to Hubli unit in 1968**,** I was made responsible for establishing the production of Motors (both 3 phase and 1phase) and Alternator products on a reasonable mass production scale before leaving Kirloskar Electric Organisation in 1973.

1.2 Introduction of my assignment

Within two years of my joining KEC, Bangalore in June 1966, the Chief Executive Officer Mr. Ravi Kirloskar assigned me the responsibility to Head of Design and Development of Single Phase Induction Motor Product with a dual reporting system; Administratively (day to day) to Mr. S Bhaskar Rao (Head of Manufacturing Unit of Single Phase Motors) for Production part and Functionally to Mr. SG Ramachandra (Chief Engineer) for Design and Development part.

In reality, I realized that I was loaded with a responsibility of reviving the health of Single Phase Induction Motor as it had skidded in the Domestic and as well as in International Market. The only market feedback available was that the Motor Start Capacitor which is used for starting purpose needed frequent replacements. None in the whole organization knew what the real problem is and why it is happening etc. Hence, my first task was to identify the real problem and then find a viable solution to counter the created poor image in Market.

2. Method adopted:

2.1 Method adopted for Investigations

I decided to visit few customer places to study the problem personally and to hear the customer's voice directly instead of through Service Manager or Engineers. It was in my first visit to Dealer's shop - through Distributer Kirloskar Brothers - at Ahmedabad (in Gujarat State) I saw demonstration of why the Single Phase Induction Motor was not being accepted in the Market. As soon as Single phase Electrical power supply was switched on, the Single phase Induction Motor started but it took long time (more than a minute although it was on No Load) to attain full speed; repeated switching indicated that the motor was struggling more and more to pick up full speed, besides, it vibrated a little in subsequent switching. In the last attempt the Motor took twice more time than that of earlier occasions. Similar was the observation during the visit to Dealers at Bombay and Pune cities.

On return to Bangalore, I studied the Product from books (Ref: Books by Veinott, MG Say, Puncheon, Lloyd and Conrad) and published papers (Ref: Paper by Micheal Chang) to trace the source of the problem through studying the Single Phase Motor's circuit which is on Page 3 and 4 of 8. My interaction with Indian Institute of Science, Bangalore (Ref: Interaction with IISC, Bangalore) succeeded in getting updates on published papers in this field.

I wish to share briefly the theoretical aspect of Single Phase Induction Motor. Unlike Three Phase Induction Motor, Single Phase Induction Motor is not self starter. Hence, initially a two phase situation is created and as a result the Single Phase Induction Motor starts rotating and when it attains full speed, the Second phase is disconnected from the circuit. In this case, Main Winding creates one phase and second phase is created by Auxiliary Winding –where Capacitor is connected- gets disconnected after the motor picks up full speed through the operation of Centrifugal Switch (mechanism that disconnects) and thus Capacitor also gets disconnected from the circuit.

Since in the above case, the focus of investigation was narrowed to Auxiliary Winding as there were no complaints related to Main Winding. Following picture and diagram are given for illustration purpose.

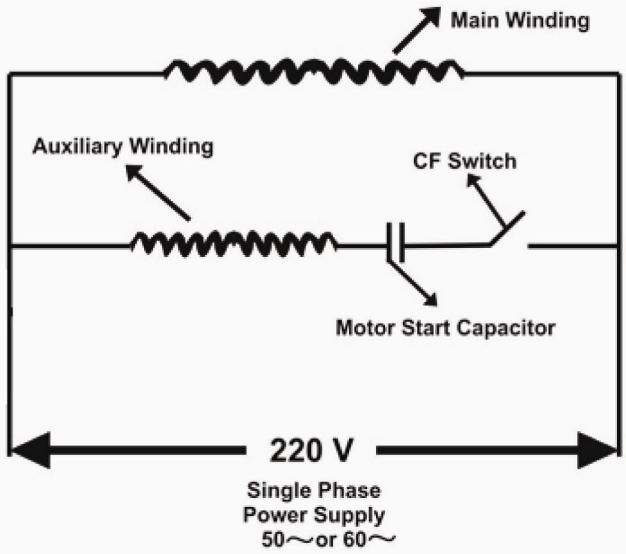
Fig 1 shows photograph of Typical Single Phase Induction Motor – which is under discussion in this article.

Fig 2 shows the Electrical Circuit Diagram of Single Phase Induction Motor. You will note that Main Winding is connected in parallel to Auxiliary Winding. Here, Auxiliary Winding circuit consists of Auxiliary Winding, Motor Start Capacitor and Centrifugal Switch that are connected in series.

Fig 3 shows Auxiliary Winding Circuit in the first part. Second part shows the whole Auxiliary Winding circuit is broken into 3 Basic elements – Resistance, Inductive Reactance and Capacitive Reactance.

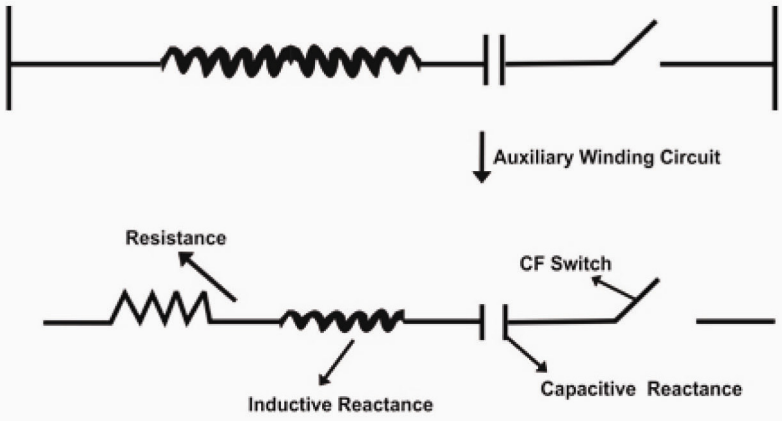
Fig. 1 **Single Phase Induction Motor Typical Application**

Fig. 2



Single Phase Induction Motor Circuit Diagram

Fig. 3



Basic Elements of Electrical Circuit

From the study, I found that there were 3 elements in Auxiliary winding circuit that were involved that could lead to failure. They were; Auxiliary Winding, Motor Starting Capacitor and Centrifugal Switch. No failure in Main Winding (Ref: Books by Veinott, MG Say, Puncheon, Lloyd and Conrad) on 3 phase and Single Phase Induction Motor) were reported. Failure Modes or possibilities of failure are in Auxiliary winding's circuit. Here all the 3 or 2 of them or just 1 of them could fail. The field reports indicated no failure of Auxiliary winding, hence looked extremely innocent. Suspicion surrounded on Motor Start Capacitor and Centrifugal switch. Establishing the non-performance or malfunctioning of Centrifugal switch was too complicated and hence the response given by the supplier of centrifugal switch that he has been supplying to Kirloskar's competitors too and he has not received any adverse feedback and this was accepted and hence, did not focus on this issue immediately, thus, allowed it to park itself.

With this, I concentrated my focus of study on Motor Start Capacitor's performance. I got few Motor Start Capacitors tested in Testing Laboratory to find out its useful life of working (Ref: IS Standard and for NEMA Standard on Motor Start Capacitor). It indicated that it was not able to meet IS Standard (Ref: IS for Motor Start Capacitor) requirements and also NEMA Standard's (Ref: Motor Start Capacitor) requirements. Besides, it was not able to deliver the declared

performance for life as defined in NEMA (National Electric Manufacturers' Association of America) Standard (Ref: Ref: Motor Start Capacitor). I reported this issue to the Supplier, CBF who was located in Belgium. Due to the language problem (I was writing in English and CBF personnel -with limited knowledge of English as they were more familiar with French) were trying to reply in English and thereby conveyed incomplete and ambiguous replies/information on technical issues. Thus, progress was very slow. Besides, it appeared that they had not understood the issue that I had communicated.

In the meantime, I looked to a Japanese source. One Japanese supplier- M/s Sakai Trading Co, Osaka, Japan who was Distributer of Hitachi Motor Start Capacitor guaranteed its performance and claimed it to be very superior to that of CBF make. The Manufacturer supported the claim that his product was fully meeting Japanese Industrial Standard (Ref: JIS on Motor Start Capacitor) - which was a step ahead of NEMA Standard (Ref: NEMA Standard on Motor Start Capacitor). The Japanese Standard was in Japanese language and to convince me of the claim they translated the Japanese standard into English (English Translation of JIS on Motor Start Capacitor). After extensive correspondence, I got was convinced that Hitachi Motor Start Capacitor was the ultimate solution that I was looking for.

At this stage, I did not stop at this point and shifted investigation to the innocent looking Auxiliary Winding. After having witnessed its slow starting at Ahmedabad, I suspected that there is a possibility of Starting torque and the Accelerating torque not being sufficient to make a quick start –say within 1 second on no load. My analysis - which included design calculations of product - proved my doubt to be on the correct track. During the investigation of design, I discovered that apart from Starting and Accelerating torque being low, the voltage developed across the Motor Start Capacitor is of the order of 450 to 500 Volts –which is very high and beyond the permissible limit of the design of that Motor Start Capacitor product of 270 V and that lead to pre-mature failure of the product.

In addition to this, the vibration that was observed during visit at Ahmedabad during accelerating period indicated that there was no torque being produced indicating possible presence of electrical resonance. In the Electrical circuit of Auxiliary winding, there are 3 basic parameters R, L and C as seen from the circuit below; in other words, Resistance, Inductive Reactance (XL) and Capacitance Reactance (XC). Then Impedance of the Auxiliary Winding's circuit is calculated as R + jXL - jXC. In case, XL becomes equal to XC, the two parameters cancel each other and the circuit will just be R (resistance). This is called as Resonance effect. With this happening, only R in circuit, heavy rush of current that flows in the circuit which heats up Motor Start Capacitor; besides, high voltage across the Motor Start Capacitor is generated due to this effect. Due to this effect, because the phase shift between the Main and Auxiliary winding becomes zero and no torque gets produced. The effect of this would be in delayed acceleration thus, taking too much time to start the Motor and vibration.

The combined effect of these would be reduced working life or in other words, the Capacitor loses its capacitance value and tends towards becoming a mere resistor. This revelation gave a rude shock to me. Then I traced as to why this has happening? Further analysis showed that the design of Single Phase Induction Motor has followed the shadow design of Three Phase Induction Motor; in other words, the Starting and Accelerating torque resulted in low or moderate. Although this suited the applications of Three Phase Induction Motors – as at no point the generation of torque reduces during the accelerating period - the same principle failed miserably in case of Single Phase Induction Motor which was being used for General Purpose Applications everywhere.

Finally, through thorough investigation and analysis, I arrived at conclusion as under;

- Existing design of Single phase Induction Motor was generating low starting torque (180% to 200% FLT),
- Low accelerating torque (around 120% to 140% FLT),
- Generating extra high voltage (around 450 V while it should not exceed 270V) across the Motor Start Capacitor,
- High voltage prevailed for about 8 to 10 seconds (on no load) leading to excessive generation of heat which accelerated the loss of capacitance value, thus failure of Motor Start Capacitor commences,
- Occurrence of electrical resonance further delayed accelerating period that lead to poor or at times no torque during the acceleration period and thus more heat generated besides, motor vibrating,
- Culmination effect accelerated the failure of Motor Start Capacitor,
- Motor Start Capacitor of CBF- Belgium make- itself was having low useful service life.

The above assignment took about 6 months from the day of assuming of responsibility of Design and Development of Single Phase Induction Motor. Having identified the hidden issues, I then turned my focus on evolving solutions to overcome the above issues.

With this, I planned the following changes on the lines of thoughts:

- Revise the Design of the Product to have High Starting torque of nearly 400% to 450% of Full Load Torque,
- Accelerating torque also needs to be as high as Staring Torque (nearly 450% to 475%FLT),
- To achieve this, work with higher air gap density than that of 3 Phase Motor,
- Ensure that voltage across Capacitor at the time of starting and as well as during acceleration period is not more than 270 volts,
- Ensure that no electrical resonance takes place from starting to acceleration period (transient condition),
- These would ensure that accelerating torque is high enough to quick start thus avoiding heating effect of the capacitor,
- As a short term plan, continue the usage of CBF make Motor Start Capacitor till alternative arrangements for importing a superior and more reliable capacitor from the alternative sources is established,
- Even after these measures, if Capacitor failure in field continues and then investigate the poor quality issues related to Centrifugal Switch.

2.2 Method of evolving Solutions:

Thus, I proceeded with the design or development of this design on new concepts and principles. In order to achieve above results, I revised the Design Procedure, selected new Design characteristics, introduced few new formulas and added few more design calculations. Thus, the design workload doubled as compared to that of the past. I chose Type D Design for the new design (Ref: Paper by Micheal Chang). Then I selected one popular and fast moving rating of the product range and kept the design ready.

2.3 Method of Implementation of Solutions:

On one day in February 1967, the Chief Executive Officer, Mr. Ravi Kirloskar happened to check with me the progress on the assignment on Single Phase Induction Motor. I explained my entire analysis of the field problem and told him as to how it could overcome. As I explained, he questioned me as to why my opinion was totally different from the one expressed many senior personnel in the organization. I plainly told him that I am not aware of what senior personnel have opined, but, I am confident that I am on the right track in identifying the real problem (fully backed by logic) and offering a solution that could completely overcome the involved issues. I assured him that I was confident that solution will successfully click well in Market as the whole thing was based upon sound logic.

Within a minute, Mr. Ravi Kirloskar confirmed that he was impressed with my confident tone and clarity on thoughts. He immediately asked what I want for implementing. I told him that I need authority to bring in many changes in one stroke. Accordingly, within next 3 days, he authorized me officially and sanctioned all the resources needed for implementing a revised design for the Product in a joint meeting with other senior personnel of the Organisation.

In the modified design, I chose the design of Single Phase Induction Motor on a concept where high starting torque and high acceleration type (Type D of NEMA for this General Purpose Application). This turned out to be the trump card for overcoming the market problem. While doing so, I had modified the Design procedure, introduced new set of calculations and introduced key process control measures to control variation of air gap in the motor and winding placement and connections so that quality built in design is carried ahead right up to the customer in field.

In order to generate high starting torque, I chose a high flux level in air gap and thus, I had to exercise a good or close control over air gap so that No load current of high order level does not exist. In view of this, I defined the close tolerance under which the Rotor machining needs to be done – for the first time in Organisation as a part of Process Control measure. This paid good dividend in Motor's performance. Besides, I trained the winders for making connection in the right way so as to create right phase angle difference between Main and Auxiliary Windings. Since the Staring Winding or Auxiliary Winding remains in power circuit for a very short time, I chose smaller wire size. The Starting or Auxiliary Winding did not get heated up when it was inactive and as a result of this usage of Copper by 25% was reduced. This Value Engineering exercise applied throughout the range of Single Phase Induction Motor range, made the Product cheaper, yet at the same time more effective in meeting all the customer needs.

3. Results

Within a month, a prototype was ready for testing based upon the newly designed model. While the prototype met all requirements of no load and load conditions, I was keen on subjecting to the field trail especially where frequent switchings are involved. As my luck was good, I got an opportunity in Bangalore itself. In this case, the Motor was

subjected to the worst application at the customer's actual place of working. Here, the customer was using a Lathe for Manufacture of fastener where a Single Phase Induction Motor was used to drive in both the directions in this application. In this case, the Motor was required to run in both directions once within a cycle of 3 mts and I considered as severe most duty. So, for the Motor Starting Capacitor, it was subjected to extra voltage (nearly double) in one cycle of 3 mts. Since the earlier Single Phase Induction Motor was having low starting torque it used to take more than 10 seconds to run up to full speed before repeating its reverse running in the cycle. Due to this, within a 3 to 4 days' time, the Motor Starting Capacitor failed and the motor refused to start.

To overcome this problem, the newly designed Single Phase Induction Motor was given for a trial in this application. Since, I only knew what the change was done, I advised the Service Manager and Engineer to keep track once in 3 to 4 days. After 4 to 6 week's smooth running the Customer expressed full satisfaction on the replaced motor. Then the mesmerized Service Manager and Engineer asked me as to what was the trick played. On explaining, both got confidence that the solution was on right track.

With a highly successful result, I had no hesitation in freezing the principles used for this design of Single Phase Induction Motor and released to Market and where it was very much welcomed. The changes that I had made were of design based new concepts of new speed-torque curve model with modified design procedure and had improved process in manufacturing process. As the result was on expected lines, the new concepts tried were put to test and they were successful. With this, the above conceptual design was multiplied for the entire range of Single Phase Induction Motors which were put in Domestic Market.

For Export Market, Kirloskar Electric was supplying where dual voltage (110 / 220 volts) model for 60 cycle supply or 50 cycle supply for general purpose application in those countries. Once the new design model /concepts were adopted for this series, the Market commenced buying our (new) product with an enhanced level of confidence. As a result of this lost market and good name was regained. With this, both the Domestic and the Export Markets were regained the lost credibility.

Besides, in order to enhance the reliability of the Product, I was looking for a reliable Motor Starting Capacitor. When I found that the Belgium sourced product CBF was not able to offer a longer life, I demanded the Type Test certificate for product having passed the reliability test as per NEMA standard. Since they failed to prove its credibility, I chose a Japanese make capacitor. However, due to non-availability of import license - under IDA loan scheme- I switched to the procurement of Daly Capacitors of UK which proved to be equally reliable.

3.2 Result of the Changes done and its effects are seen at a glance

Sr. No.	**Performance parameter under Review**	**In earlier System**	**In New (Redesigned) System**	**Effect**	**Remarks**
1	Starting Torque	180 to 200% FLT	400 to 450% FLT	High torque developed	High torque developed
2	Time to attain full speed on No Load	10 to 20 Sec	1 to 1.5 Sec	Quick starting	Quick starting
3	Time to attain full speed on 100% full load	60 to 80 Sec	Less than 3 Sec	Quick gain of full speed	Quick gain of speed
4	Voltage across Capacitor	470 Volts	Not more than 270 Volts	Voltage across within permissible limit	Long working life in field
5	Presence of Resonance	Yes during acceleration period	No resonance during accelerating period	Generation of torque on continuous basis	Smooth acceleration taking place
6	Capacitor heating effect	Used to become hot during acceleration period	No during at any moment during acceleration period	No heating at all	Long working life in field

Kirloskar Electric's Single Phase Induction Motors were conforming to IS 996 Standard (Indian National Standard) (Ref: IS 996 on Single Phase Induction Motor). Since the design based upon the concept that was unsuccessful in the Markets, I proposed a change in IS 996 to adopt the new successful concept (of having high starting torque in place earlier values). The Sub-committee of Indian Standard studied the proposal and incorporated the changes in the Standard after the same was endorsed by the Technical Committee.

A year later – in June 1968, Chairman of Board of Directors / Management, Mr. NW Gurjar along with CEO, Mr. Ravi Kirloskar in a personal meeting complimented me for having made an excellent contribution done by producing a trouble free Single Phase Induction Motor design which has been well received in the Market. In recognition of my contribution to the Organisation in regaining the lost market and gaining the customer acceptance, apart from expressing satisfaction he announced my promotion along with a transfer to KEC's Hubli unit.

4. Discussions

4.1 Few key challenges faced

- My own limited experience,
- Switching from Factory focus to Customer focus,
- No technical support in form collaboration in those days for this range of product,
- Incomplete and ambiguous field reports,
- Had to learn to evaluate effect of transient conditions,
- Language problem with Belgium Supplier of Capacitor,
- Changing thinking culture.
- Building quality mind in Top and Senior Management personnel,
- Had to learn the use of FMEA tool.

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The Author thanks the Top Management, Senior Managerial level personnel and Members of staff at different levels in Kirloskar Electric Organisation at Bangalore for implementing of above solutions. The Author appreciates the excellent moral support rendered by Chief Executive Officer, Mr. Ravi Kirloskar and Chief Engineer, Mr. SG Ramachandra during this period.

The Author thanks Authors of 3 books (Ref: Books by Veinott, MG Say, Puncheon, Lloyd and Conrad) who provided basic knowledge of Three and Single phase Induction Motor, Indian Institute of Science for guiding to look for right published papers, Sakai Trading Co for having provided the knowledge on Motor Start Capacitor conforming to Japanese Industrial Standard and also NEMA whose Standard on Motor Start Capacitor opened the eyes on what to look in the product.

Finally, the Author thanks Bureau of Indian Standard for having accepted the suggestions made to revise the Standard (IS 996) that provided guidance to other Indian Manufacturers to follow in the design of motor.

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