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By Prashobh Karunakaran

Abstract- This research is timely because many High Technology Product Producing Factories (HTPPF) are still following the trend of factories that produces the likes of canned food or even cars where all machines are jointed from start to end. Many HTPPF have not realized that improvements to product must be done every day to keep market share. And to perform research continuously, buffers in-between production machines are absolutely necessary. The absence of such buffers has caused a many hard disk manufacturing factories to close down especially in the Japan, Korea and Taiwan (notably Sony, NEC, Matsushita, Samsung and Trace). These factories were leaders in joining up production lines from start to end; but discovered that it led to a disadvantage in their ability to perform the necessary continuous improvement in product quality and capacity. Decision makers in these factories thought that a dedicated research line is all that is needed for research. This paper explains why a dedicated research line is not the answer to the needs of a HTPPF. Currently 90% of hard disks are produced by Western Digital and Seagate, with Toshiba having 10% market share. Western Digital and Seagate were slow in automating production lines which benefitted them in their research capability.

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I. INTRODUCTION

Buffers in-between production machines enables research initiatives in production machines. The main reason why researchers prefer to perform hypothesis test on the production lines rather than on a dedicated research line is the empirical fact that in HTPPF, upon start-up of a line there is a yield drop and this yield stabilizes to the normal high value only after a few hours but can even take a day or two. This work was done mostly in computer hard disk factory but the same scenario is reported in the silicon chip industry. Therefore upon startup of a research line, a researcher may have to wait for up to two days before even a small change in say one chemical in the long production line can be tested. This discourages researchers from using the research line. Comparatively in a production line where the yield is already at around 98%, a small change in chemical in one particular machine in the long line can more easily be deciphered at the final test machine. Also if production lines are used as test beds many lines can be used at once, so more samples and controls can be taken. Research lines are still available for major changes especially where big

electromechanical changes to machines are involved, but for quick validation of results, the running production line is preferred [1]. This author had fourteen years of working experience in the Western Digital hard disk factory in Sarawak, Malaysia, where research is done every day to improve the Key Quality Characteristics (KQC) of hard disks.

II. LITREATURE REVIEW

Initially a review of how manufacturing started and how it ended up in the current state was studied. Manufacturing started with Custom Manufacturing. In Custom Manufacturing, a carpenter made furniture, a cobbler made shoes and a tailor made clothes. These people had all the skills required to make the entire product. Today, special projects like spacecraft, special furniture, special clothing and specialty robots made by research organizations are still custom manufactured. As demand grew these skilled craftsmen could not meet the increasing demand of the people so Intermittent Manufacturing was developed. This is a set of small factories where products were made in batches like a batch of ten brooms at a time. The parts for a product are made at a time. Say ten wooden rods are turned from the raw wood. Then ten bottoms of the brooms are cut to shape from the raw wood. Then the ten bottom of broom are drilled with holes. Then the holes of the ten bottom of broom are stuffed with the plastic brushes to make the final broom. Continuous manufacturing was first developed in the Ford Motor company. There was a continuous demand for the Ford Model T cars so a conveyor system was developed where workers added parts to the cars at each station [2].

That was the beginning of the human drudgery of performing repetitive tasks like machines in factories. Instead of manufacturing say only ten brooms at a time, a continuous output of brooms are manufactured. At each workstation a particular task is performed to make the broom. Workers at each station are trained to accomplish their task as quickly as possible. Today most consumable products are manufactured in this way except that human are often replaced by robots [3]. The next manufacturing system is called Flexible Manufacturing System (FMS) where computer and communication technology is increasingly utilized. In a FMS, products are manufactured in lots but the process is continuous and highly automated and generally

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controlled by a central computer. FMS is a group of computer-controlled independent machines linked by material handling systems that are able to produce a variety in types and quantities of products. All the machines are controlled by a central computer running a Human Machine Interface (HMI) software which normally includes a SCADA (supervisory control and data acquisition) system. Often there are no humans even at the HMI computer. Many HTPPF management mistakenly believe that is the ultimate trend and work toward automating everything without buffers, thus hampering research initiatives. A HTPPF needs continuous research and only humans can do this. If the whole factory is already like a machine, humans cannot make changes easily. They cannot even access the machines because factory robots can harm them. Many HTPPF and not designed with the researchers' access in consideration. Researchers have to stop the whole factory or at least a whole production line to test out a hypothesis.

Since factories are increasingly being automated, details of the latest available robots and capabilities were also studied. The available configurations of robot arms are SCARA (four axes robots - Selection Compliance Assembly Robot Arm), Vertical multi-joint (six axes robot or articulated), Cartesian coordinates (two axes also known as Linear Module). Cylindrical coordinates (two linear axes plus one rotating axes) and Spherical coordinates (one linear axis plus two rotary axes).

Most of the testing used in this work is at the University Malaysia Sarawak laboratory which has five Adept robots of various configurations. The Adept Cobra i600 is a SCARA robot. It is the first Adept robot with the amplifier unit built into the robot arm. So it is not far off to place the PLC and everything the robot needs in the arm. The head of Adept robots in Singapore stated that it is just a matter that no one demanding for it so far [4]. Robots can change End-Effectors which are like changing fingers according to the type or shape of the product it will pick up. The Teach Pendant of the robot is used to move the end-effector to the product being processed and then this location is stored as a variable (like X) with the instruction: "here X". Later to move to this particular location, the instruction used is: "move X". The teaching of the location of the product must be extremely accurate because sometimes the robot arm have to move to this particular point to pick up the product for 24 hours a day and for many months after the initial teaching [5].

Major developments in factory machinery especially to prepare for future product generations are slow due to the huge capital invested in existing HTPPF machines and the large amount of capital such industries generate. The view that a process that is still generating big income requires no update is what kills

big companies. The huge scale at which a HTPPF can be is best depicted by the largest, located in Shenzhen, China. This factory named Foxconn utilizes about a million workers to create revenue of US\$94 billion in 2011 [9]. With such big money and number of employees, the resistance to major changes to cater for future generation of products is much greater. Foxconn is mostly an assembly factory but there are lots of avenues of improvements to make such a factory more efficient. Continuous research can be done aided by buffers in the production line.

A general view is that big companies with highly educated people cannot make major mistakes. A classic example to counter this is IBM. IBM invented the hard disk and was the main hard disk manufacturer in 1994 when it started to change the hard disk media from Al-NiP to glass. IBM was so confident that this is the direction to take that they shut down all their Al-NiP plants while the rest of the hard disk industry stuck with Al-NiP. The reason why glass was thought to be superior was that it was better able to handle head crashes onto the disk. If the head crashes onto the Al-NiP, it will cause a ripple just as when a stone is thrown into a calm lake. This ripple destroys lots of data [6].

The problem is that there is a huge data base on metallurgy developed since mankind started making swords while glass is a relatively new material. Therefore while Al-NiP factories were able to continually increase data capacity of their hard disk, IBM struggled. The Al-NiP factories also later developed systems that prevented the heads from ever contacting the disk via various sensors placed within the hard disk. As an example when a laptop is falling down, the head will move up over the disk, just as weight decreases in an elevator that moves down. A sensor is placed to detect this and the head is instructed by the software to immediately move completely off the disk. With sensors like this Al-NiP hard disk manufacturers claim their hard disk can take a falling force of nine g-force. This practically nullifies the advantages of using glass to make the disk in the hard disk [6].

Another major issue was that glass cannot dissipate heat generated as the disk spins below the head, while the AL-NiP disk can dissipate it via the hub which clamps onto the disk. From the hub heat is transmitted to the relatively big surface area aluminum body of the hard disk.

Heat destroys magnetic data storage. Magnetism occurs when electrons in domains within magnetic materials, like iron spin in the same direction. Heating a magnet will make electrons spin clockwise in one domain and anticlockwise in another and so forth. This in effect will turn the material back from a magnet to iron. The end result of this wrong decision by IBM researchers is that they had to sell off the entire hard disk manufacturing division [8].

III. METHODOLOGY AND RESULTS

The methodology and results for this work was done via data collection and empirical observations at the Western Digital hard disk manufacturing plants in Sarawak and Johor, Malaysia and also the laboratory at University Malaysia Sarawak.

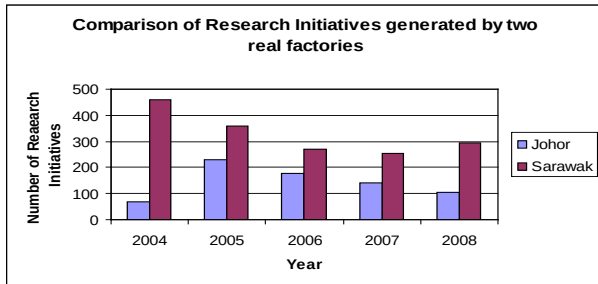


Figure 1 : A comparison of Research initiatives generated by two factories, the Western Digital factory in Sarawak (with buffers in-between machines) and Johor (with no buffers in-between machines), Malaysia

Data was collected of the rate of research activities for the Western Digital (WD) factory in Johor, Malaysia which is fully automated without buffers, versus the WD factory in Sarawak, Malaysia which has humans operating the buffers in-between automated production machines. The results are depicted in Figure 1. In the current hard disk industry, companies are still bent on full automation (without buffers) neglecting the above data; the exception being WD and Seagate which in recent years are following the Sarawak factory model. It is not the human factor in these buffers that enabled the Sarawak WD factory to have superior research but the fact that researchers can stop production lines due to these buffers. Humans in these buffers cause lots of defects as they handle ever increasingly sensitive hard disk media. The aim of this work is to automate this buffer so that researchers can more easily perform their tests.

The logic of managers of HTPPF in justifying fully automated production lines without stoppable buffers is that research can be performed on the dedicated research lines. But empirical observations made at the Western Digital factory in Sarawak showed that researchers tend to avoid the dedicated research lines and prefer to use the production lines to perform their tests because of the following factors:

- a) Faster manpower turnover in a research line. A research line of production machines need a whole team of technicians to operate and maintain. Researchers will find it hard to justify financing this team to top management who tend to value short term or quarterly financial gains. This research team could be idle for days in-between research activities and this could be frowned upon by the rest of the

production staff, especially during performance reviews which will eventually lead to employees deserting the research teams.

- b) The current process must be stabilized before introducing a change. An empirically observed situation is that unfailingly, a newly started production machine will always have more defects, especially mechanical defects and particles than a line which has been running for a few hours. It might take even a full day for yield to go back to 98-99% after Preventive Maintenance (PM). Engineers in factories are still baffled by this empirical observation which goes against logic because machines which just went through PM have new parts and a thorough cleaning of the machine is always done after PM. In fact people in charge of PM in factories are often blamed for this issue. This is especially the case if the management does not have a technical background. Management can be engineers without much hands-on practice of non-engineers.

The most probable cause is not the mechanical parts but the fact that the stirred up chemicals in a machine that has been running for some time is more conducive for the process than chemicals that have been stagnant for a day or more. One of Western Digital's (formerly Komag) factory in Japan, concluded that even if the inner circumference of the pipes are clogged with coagulated chemicals, the process is still stable unless these pipes are disturbed by the PM, which dislodges particles from the inner circumference of the pipes. The PM for the pipes involves pumping either hydrogen peroxide (H₂O₂) or nitric acid (HNO₃), (depending on if the process chemical is acidic or alkaline respectively) in the pipes for a duration of one to six hours (minor or major PM respectively). It is for this reason that PM on the pipes was not done for this Japanese factory. Instead all the pipes are changed after a certain span of time.

- c) Other than chemicals in pipes, HTPPFs uses other OSRM (Operation Supplies Required Materials) which includes filters, liquid abrasives and specially built porous pads that hold the liquid abrasives required to polish the computer hard disk media. All these OSRM do not function optimally if they are not wet or used over a few hours. Settlement or coagulation will occur in these OSRM which impacts yield.
- d) More samples of the test can be carried out in production lines. A researcher can test out an idea on say five production machines and take another five lines as controls. With more samples the conclusion can be more accurate than using just a research line. The overall change in the quality of the resulting product due to the incremental

research change on the product is often very small and deciphering a conclusion of its impact to final yield is quite difficult. So the more samples and controls there are, the easier the research objectives are achieved.

- e) Researchers will eventually have to justify cost like everyone else. They have to plan their annual budgets. Starting up a huge research line for a tiny molarity change in one of the chemicals used in the production will definitely be very expensive and hard to justify at the end of the financial year especially if the results do not positively improve product quality. The cost includes employee compensation, increasingly expensive chemicals, electricity and extra Clean Room expenses. Clean Room expenses include electricity and HEPA (High Efficiency Particulate Absorption) filters and ROI (Return On Investment) of building the extra cleanroom. Considering all this justification to financially impatient managers will result in scientist performing less research. Researchers should not be expected to achieve a positive result for every hypothesis they made.

Considering all these potential problems of running a newly started production line, researchers tend to prefer performing their test on production lines which are continuously running every day for 24 hours. Note HTPPF run production 24 hours because settlements and coagulations of chemicals will not allow production to stop. Therefore because of the cost implications (and therefore management approvals) of performing even a small test, buffers between production machines in HTPPF are a necessity.

Other than aiding research initiatives, buffers will enable maintenance to be carried out more easily. Say a small pneumatic cylinder is faulty in one machine in a long production line. Buffers will enable the maintenance crew to stack up products in the buffer and repair the pneumatic cylinder. Without the buffer the whole production line will have to be stopped to repair this small pneumatic cylinder.

Throughput improvements of a particular machine within a long line can also be made easier with buffers within production machines. Say an engineer designed a throughput improvement for one machine within a long production line. If there are no buffer in-between machines, the throughput improvement cannot be utilized because all machines in the line must be synchronized. On the other hand with a buffer, improved throughput of one machine translates to a larger buffer before the next machine, while waiting for engineers to design throughput improvements for the next machine and so forth.

Another justification for a buffer is that it enables running multiple products. For example, with buffers

products can skip one machine in a long production line. Perhaps customers have requested for such product for a lower end application. By the same token buffers can enable a higher end product as the product goes through an extra machine or two for a high end military application for example.

To enable an automated buffer the first design was a robot installed upon an elevator in-between HTPPF machines. As mentioned previously humans in buffers do not specifically enable research but a stoppable buffer does. Humans actually tend to create handling defects to the increasingly sensitive hard disk media; as the data stored on it increases at an exponential rate. So automation need to be designed such that the buffer can be stopped by researchers without human handlers.

The disks are placed in RFID coded cassettes and stacked on three layered tunable shelves. The reason for three layers is the standard dimension of floor to roof in a hard disk factory and the size of an off-the-shelf, six-axis factory robot. For this buffer to have more layers the robot arm must be custom built. The robot moves up and down with the help of a ball screw. Moving robots up and down on a ball screw system has never been done before [4] because factory robots have facilities going up to it.

Currently most factory robots have a CPU and an amplifier to amplify the signals coming out of it before it goes into the robot arm. Currently one Adept robot, the Adept Cobra i600P has the amplifier unit built onto the robot arm. But it is possible to build-in both the CPU and the amplifier into the robot arm [4]. The facilities required are power wires, signal wires and pneumatic pipes.

Wireless power is a recent advance developed at MIT (Massachusetts Institute of Technology) [7]. Basically a normal 50 or 60 Hz power transformer already has wireless power transfer between two coils separated by a paper. If the frequency is increased to the megahertz range, the separation of coils can be up to many meters.

As for the wireless signals to the robots, Wireless transmission has long been around as in cell phones but has not been implemented for factory robots, mainly due to concerns of hackers penetrating the factory robots. Therefore to communicate signals wirelessly to factory robots, security software must be sourced or developed from established suppliers (like McAfee).

For the electro-pneumatic system within the robot arm, Clean Dry Air (CDA) supply can be sent to the robot arm by installing a small pump with a filter at the robot arm itself. And this pump runs on wireless energy from the base at the bottom. Figure 2 and Figure 3 shows a Solid Works picture of the automated buffer.

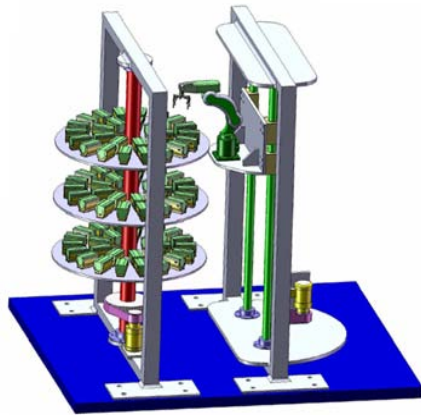


Figure 2 : The design of the buffer system in-between machines (Solid Works software sketch) which will facilitate research initiatives in HTPPF

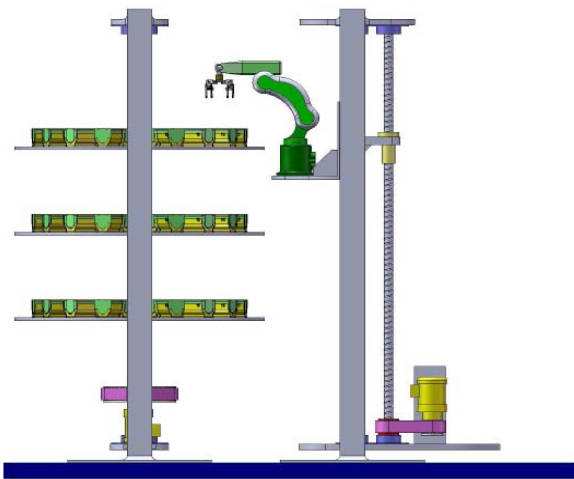


Figure 3 : Side view of the automated buffer

Once the automated buffer has been designed, there is a need to design a better way to stop the production machines. Researchers need to be able to stop production machines upon getting an inspiring idea without causing damage to products. Currently when a researcher stops the production line it is quite messy, with products being manually placed in temporary storage containers (if wet) or in cassettes on carts while the researcher makes the changes. This current system requires lots of human handling and therefore damage to the products. Quality personnel or managers will be shocked to see the avenues for damage to the highly sensitive products as they just pass by a production line being stopped by researchers. So a novel machine stopping method was designed specifically to cater to the needs of researchers within HTPPF.

The designed improved stopping device called Machine Stop (MS) has three modes of stopping. If Button I pressed, the machine will stop with memory i.e.

stopping just like an EMO (Emergency Machine Off) does, but the machine has memory of last positions before stopping. This is enabled with the help of the recently available encoders with battery backup. Thus the robot will not need to do a "homing" upon startup. Homing need to be done if encoders are without battery backup so that the main controlling computer knows exactly where its' parts are.

If Button II pressed, the stopping will occur after finishing the current process. Say a machine has nine processes and the researcher may want to stop it after the second process to test an idea, so the button II must be pressed during the second process.

If Button III is pressed, all the existing products from the machine will be cleared before stopping. To enable these modes of stopping all the actuation of production machines must be changed from electro-pneumatics to battery-backed-up-encoder servo motor as depicted for a cleaning machine in Figure 4. In a high level portion of the program there is a continuous monitoring for button I, II or III being pressed by a researcher. If I is pressed for example, the program counter jumps to a sub-routine to stop the machines and record all the encoder positions of all the servo motors.

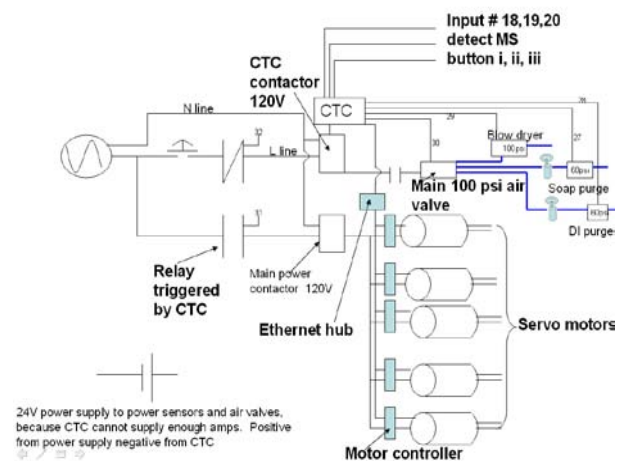


Figure 4 : A disk cleaning machine wiring schematic to enable Machine Stop (MS). The bigger bold letters represent changes

IV. JUSTIFICATION FOR AUTOMATION

With all these innovation implemented, the factory will have less manpower. There is therefore a need to justify advancing automation in factories as there are some who claim that such advances will take away jobs from the workforce. But paradigm shifts need to be made to view these automations as instruments that can liberate factory workers from the inhuman drudgery of pick and place jobs. Peering into human history will reveal that it was never natural for humans to be doing repetitive jobs for eight to twelve hours each

day. Currently factory workers keep performing their jobs for the financial benefits they gain, the money is the shackle that keeps them almost as slaves to their jobs [10]. This prevents them from having the normal human intuition to help improve their surroundings. Their tight work schedule prevents them from developing skills that can enable them to earn a living in other ways. Factory work should be relegated to the machines. Foxconn factory is the largest private sector employer in China. In 2010, 14 suicides occurred in the factory and the factory actually installed nets to catch people falling down [9, 10]. Margaret Heffernan studied the problems in Foxconn and found that while it is the most modern factory in the world, economic needs have resulted in the management squeezing the workers of every last bit of energy. The workers are monitored constantly to ensure they are as efficient as possible. Basically management in this factory are watching over their human workers as any diligent management will watch over a factory robot to ensure it is positively earning for the factory. Often they do this without the concern or respect a football or basketball coach has over their players. Thereby the workers feel squeezed of every ounce or dedication they can provide and this sometimes leads to suicides. Workers were initially enticed to work in the factory on the first day by higher salaries and the possibilities of ending up as an entrepreneur like Bill Gates or Steve Jobs [11]. Only later they will find out they will have to be the agile robots that scientist and engineers have not yet been able to create (at the cost of their salaries) [12]. Workers join these factories in the hope of achieving their dream of financial success but more often than not they exhaust their human capacities instead. By the time they are retrenched (which is common) they realize what a foolish mistake it was to spend 10-17 years specializing in a skill within a HTPPF which cannot be utilized outside the factory. A worker who initially opted to be a construction laborer, a grass cutter, an electrician or a farmer will have more chance of continually upgrading their skills and eventually using these skills to better their financial status. The chances are higher for a construction worker to end up owning a construction company, a grass cutter to end up owning a landscape business or an electrician to end up owning an electrical installation business, than a Foxconn worker ending up owning a HTPPF.

Industrialist and job seekers have to come to terms with the fact that, with today's international market place, customers from a rich or poor country will not purchase an inferior human-labor made product, while a superior quality and cheaper, robot-made part is next to it. People will only purchase the optimum product to suit their finances and needs and not to satisfy some patriotic ideal. It is therefore imperative that competition will cause the human-labor intensive factories to eventually shutdown. When this happens, the only

factory where a human can get employed will be as researchers at automated factories, which are producing high quality products at the lowest cost. Thus to increase employment, industrialists need to use automated machines and processes to find a niche in the international market. By slowly building up this niche with higher quality and precision, they will increase employment. Eventually HTPPF will be populated only by researchers or other highly technical skilled workers, most probably all degree holders [12].

V. CONCLUSION

The main hypothesis of this research is that buffers in-between production machines will enable HTPPF to innovate and thereby keep market share. The proof for this is the empirical observation that researchers in the WD factory in Sarawak prefer to use production lines to test their hypotheses. Also the chart Figure 1 indicates that the WD, Sarawak factory, which has manually operated buffers in-between machines, has a greater rate of research compared to the WD, Johor factory where all machines are jointed up.

The other data is the empirical observation that HTPPF that do not have the understanding that buffers are important are losing market share or have closed down especially in Japan, Korea and Taiwan. These factories automated and joined up all machines without buffers because it is the trend in all industries to do so. Top management tend not to be the most technical people in the factory some are non-engineers or engineers who skipped the hands-on work and rose into management. In the hard disk industry a company that cannot make the transition from one level of hard disk capacity to the next, say from 80GB to 120 GB per platter, can close down within a quarter or two.

In many of these failed HTPPF, top management reasoned out that dedicated research production lines is all that is needed to perform research, but as empirically observed, the research lines are frequently left unused in HTPPF, unless there are major changes to the product. A majority of the changes to product quality are small and can best be performed upon a production line.

VI. FUTURE WORK

Having used the WD factory as a research laboratory, four future works is suggested for improving the production flow in HTPPF.

The first is a better statistical software coupled with easily placed sensors to enable factory engineers to more easily trace yield detractors within HTPPF. Statistics used in factory are gradually developed and improved in the production of products but as life spans of high technology products decreases the statistical methods used should be as made as easy to use as possible.

The second improvement is a similar statistical software coupled with sensors to trace less than optimum operation of machines. For example a vibration sensor can detect a faulty bearing before the problem escalates to the destruction of an induction motor. This will reduce down time of machines, increase yield and bring down overall production cost of the HTPPF.

The third improvement should be to bring down prices of ultrasonic sensors, which are installed outside pipes to detect flow rates within it. Current propeller and ball flow-rate sensors are becoming too inefficient and sources of contamination in HTPPF. As chemicals used in HTPPF gets purer to cater to the ever increasing capacity in smaller spaces, required in products (like hard disk), contamination from propeller flow meters becomes unbearable. Furthermore, while installing propellers flow sensors, pipes need to be cut which will contribute to the contamination of chemical lines. Propeller and ball flow meters currently used in HTPPF tend to stop working after a while as sedimentation of the chemicals or even the extreme pH levels of these chemicals prevent their optimum functioning.

A fourth improvement is the more extensive use of fiber optic sensors. Fiber optic sensors can recently measure most physical properties ranging from strain pressure, temperature all the way to pH of chemicals [13]. These sensors are also non-reactive to most chemicals and withstand extremely high electromagnetic surroundings. So research should be advanced in this field to bring down cost to affordable ranges for use in HTPPF.

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