My Philosophy on

Machine Design, Engineering and Development

of Prototype, one-off Machines and Production Systems

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Designing, building and installing a unique machine or system for your customer requires a seemingly endless stream of decisions to be made. Each of the thousands of assessments involved has the potential to substantially impact subsequent evaluations and decisions in the chain, either positively or negatively.

These decisions which determine: the design and engineering details; the specifics of the machine's performance, maintenance and life cycle; and the training and effective interaction with the personnel involved, are also affected by safety regulations, environmental issues and legal concerns.

Depending upon the final destination, factors to be considered also include international law, local regulations, and the politics and culture of the countries involved.

Large or long range projects are subject to a turn-over of personnel during the evolution of the integrated teams. It is necessary that continuity be maintained through successive teams to ensure a smooth transition with cooperative cross team collaboration during the design and development of a machine, and throughout its installation, commissioning and customer training.

Each assessment has the potential to influence subsequent decisions, and each decision can affect the choices that follow. The reasoning for each decision, and the results that are expected, should be recorded, as well as the changes that may be made as more data is compiled. Out of this vast number of assessments and decisions there are a large number that would be too insignificant to record, such as those that would just be the following of good design and engineering practice. However, the decisions which relate to the uniqueness of a prototype, or one-off machine, should be clearly documented. These records will serve well as a basis from which to trouble shoot and further develop the specific areas where unforeseen problems may arise.

The wide range of detailed engineering calculations that are necessary during the creation of a machine should be meticulously recorded to facilitate an in depth examination of a particular design aspect should corrections or modifications be required. Comprehensive records are also essential to ensure that a continuously evolving team is able to easily see how the progressive steps of the planning, design and construction of the machine have developed.

Pressure on industrial machinery manufacturers is increasing exponentially as competing machine builders pursue ever decreasing costs, while at the same time responding to their customers' demands for faster, more versatile and safer operator friendly machinery, with the flexibility to produce a wider range of products with little or no set-up or changeover time, while requiring minimal maintenance. At the same time the end users expect a lower capital cost that will provide a greater return on investment, in addition to their demands for processes that are 'green'.

In striving for higher speeds, more versatility, and greater economy, machinery manufacturers have long since moved from manual controls and mechanical drives to: servo motion control systems, the use of machine vision to sense product or machine variations with autonomous responses to affect the necessary adjustments, mechatronics, and the IIoT; all of which result in better management of the manufacturing processes. This of course, has introduced much greater complexities, not just into the finished machine, but very much so into the art of designing, engineering and building such a machine or system. On the other hand, for some processes, the machine and control system might be much simpler.

The multidisciplinary ensemble of engineering talent that is necessary to undertake a large machine/system design and build project will require: research and development management skills; familiarity with the technologies expected to be incorporated; design engineering expertise in each of the disciplines involved; 3D CAD and CAM proficiency; experience with electrical and electronic design software along with the skills to run and debug a virtual control system before it becomes a physical reality; and the use of a secure document management system.

Before beginning the design phase of developing a machine or production system, a feasibility study will undoubtedly have been conducted covering the economic and performance criteria that would indicate whether a custom special purpose machine or system would indeed be required to achieve the desired end result. At this point a recent market study or survey will also have been completed, which would provide strong support for the type of machine or production system that would be required to meet the projected needs. The studies should have determined the basic parameters, the level of productivity and the quality required in the end product, as well as the general magnitude of the costs that can be supported while meeting the projected production targets and the expected ROI over the life of the machine.

It should be kept in mind that a one-off machine, a prototype, will probably require some modifications before it is able to reach its productive potential. Mistakes will occur, better ideas will flow and the designer needs to be flexible and adaptable, and to be able to easily alter course as new data becomes available. Before building a physical machine, 3D models of the critical areas should be 'constructed' with some animation being run to accomplish the initial debugging.

Unlike mass-produced machinery and equipment, custom one-off specialty machines do not warrant their manufacturer investing in expensive unusual tooling and dedicated machinery to produce just one particular machine. A one-off specialty machine should be designed to take economic advantage of common materials and sizes and to incorporate standard commercially available components wherever possible.

A well designed machine or system should easily meet the customer's goals in: overall efficiency, savings in material costs, lower labor costs, durability, reduced impact on the environment, lower energy consumption, utilization of less floor space, minimal waste and scrap, etc.

A custom special purpose one-off machine, where feasible, should be designed to allow for changes and modifications to upgrade the machine to meet future expected needs. However, this is a judgment call, and it is easy to miss the mark in predicting the future requirements of the market. Unless the anticipated needs for future upgrades are obvious, one should not incur extra costs just on the off chance that a particular change or modification might be required at a later date.

The design criteria developed from the product marketing analysis should detail all that the machine is intended to achieve, along with an outline of the related preliminary engineering that will be required to give an overview of the technical hurdles to be overcome. As well as the target efficiency, a threshold for the unit cost of the product should be determined.

It is necessary that the designer understands the effect of tolerances on not only the quality of fit and the mating of parts, but also on the precision and quality of the items being produced. The utility of a component will, in large part, dictate the tolerances to be specified for a particular application.

It is essential to have frequent design reviews which would include the engineers, designers and their colleagues, with separate reviews to include the customer, all of which would include scheduled targets. It is also important that the designers continually improve their skills and techniques with the latest software common to the team.

The level of advanced technology incorporated into a machine is critical; too much sophistication can unnecessarily increase the capital, training and operating costs; and too little can result in longer set-ups, with the necessity of overruns to replace spoiled product due to inconsistent quality.

It is important that the marketing, engineering personnel and the customer fully understand the legal and ethical ramifications of the use of whatever chemicals and/or dangerous materials that may be involved, if any.

A preliminary proposal should then be developed to determine if all of the criteria can be met, or what percentage can most likely be achieved. It will be necessary to include some preliminary engineering to determine if the targets are within the achievable range. It should be confirmed by this point whether suitable standard commercially available machinery can be purchased to meet the requirements, if available equipment can be suitably modified to fill the requirements, or if it is indeed necessary to design and build a custom special purpose machine to meet the demands of the market. The refurbishment, modification and reconfiguration of used machinery might also be an alternative.

Regardless of the conclusions of the foregoing, the next step would be to develop a full proposal for either the required custom machinery or for a standard commercially available machine, complete with cost estimates for modifications should they be deemed necessary, and documentation detailing the expectations, the risks and the net benefits.

Regular interim reviews should be conducted throughout the process of developing a full proposal so that adjustments can be made when new information is presented.

After it has been demonstrated that the project is both economically and physically feasible, and the proposal submitted to, and approved by the customer, the machine design engineer can now turn their main attention to the design of the machine or system. There should be customer input throughout the design process and it should always be considered valuable. There will be times when a designer, or design team, will feel that some of the input is not relevant, but it should all be considered for what it was intended to offer to the project.

During the proposal phase it will have been necessary to determine the amount of space required to accommodate: the machinery or system, the necessary support equipment, the storage of raw materials and finished product; and whether located indoor or outdoor. Besides the physical dimensions of the foregoing, positions of openings such as doorways, windows, ventilation, etc., should be determined. The locations and details of services; e.g. heating and/or air conditioning systems, electrical power, overhead power lines and clearance, buried power cables, natural gas supply, propane gas storage and supply, water supply, telephone cables, radio transmission towers, and shipping and receiving areas with their loading and unloading capabilities, either existing or planned, should also be included. It may also be relevant to take into account highway and roadway capacities and access points, railway sidings, airport services and plant security.

Even though the civil and architectural engineers will be responsible for determining the geological conditions and researching the history of the site to determine if there are any previous land fills, excavations, foundations, cavities such as disused sewers or other types of tunnels used by a previous industry, buried toxic wastes or forgotten cemeteries, the designer should be aware of the data which those engineers will have uncovered. In some locales there is the possibility of archaeological finds, which may impact the time line for the construction of foundations, etc. The depth of soil over rock, water table or other underground conditions should be determined, as well as the planned locations of any pits or underground services. Factors introduced by climatic and environmental conditions, e.g. wind, temperature, humidity and seasonal changes, etc., should also be noted, as well as the geographic coordinates and elevation of the intended site.

Besides the essentials of machine design, it is very important to keep in mind the dimensions of the sea-going shipping containers or other conveyances, their capacities, and the configurations that are available. If roads over which the containers will be transported include switch-backs in mountainous areas, or if the unloading space at the final destination is limited, it may be necessary to use only 20 foot containers. The machine sections or subassemblies must fit into or onto the selected transportation containers or equipment.

It is not unusual for something unforeseen to happen where local machine shops and/or other services are urgently needed to keep the installation on schedule. Contingency plans should be developed during the design phase to address these particular needs. These plans should include the names of the organizations and/or individuals, their proximity to the installation and the names of those who may be called upon in case of these eventualities. It would be prudent to make arrangements for these services ahead of time.

It would also be wise to determine, in the event that unions are involved, the ground rules for a good relationship with the unions.

Designing a prototype or a one-off production machine that will function as expected from the start-up/commissioning through its intended working life, requires a great deal of thoughtful research and development, and careful planning. The design engineer and their team only get one shot at this machine or system, and it must achieve the intended results with no retries – a bit like a moon shot. A successful project can be quite inspirational for the machine manufacturer's team and for all those involved who may contribute to the success of subsequent projects.

An essential aspect, which requires serious consideration, is the expected quality of the product to be produced, the quality of the material to be processed and how the precision and quality of these affect the production process. Through necessity, this will also include the accuracy of the monitoring/testing equipment which would be incorporated into the production machine or system. In addition, the life and total anticipated number of product units or the number of cycles must be included in the calculations to ensure that the machine will remain efficient and reliable throughout its intended life and will yield the expected ROI.

Even though an efficiency rate in excess of 90% for an automatic machine might be projected, considering that this would be a custom one-off machine, basically a prototype, a conservative efficiency rate of 75% should be applied to the calculations for the expected output to take into account the unforeseen factors that are likely to emerge. There will probably be shifts when the average efficiency will exceed 90%, but there also may be periods when it is less than 50%.

All aspects of the training regime should be carefully planned to not only instruct those with previous relevant experience, but also to teach those who are new to production processes. Procedures to address personal injuries and other emergencies should be developed, as well as plans for quick and efficient recovery from damage to the machinery should that occur.

Even though not functional, the aesthetics and ergonomics of the machine are important. If the machine or system is pleasing to the eye and easy to operate, the operating crew will have more respect for the equipment than if it were an ugly difficult beast. The owners and managers would also have more confidence in the machine. And the appearance of the machine can impress the customers, either positively or negatively.

Working back from a target completion date, a scope of work, including as much detail for each of the phases as can be determined at this early stage in the planning, should be included. Notwithstanding the uncertainty and risk in designing and building custom, one-off machines or systems, custom designed and built equipment can be created and be up and running on schedule and on budget. However, the time-line and the budget must be very tightly managed.

The project should be divided into sections or areas of responsibility where the responsibilities for each section or discipline are assigned to the different members of the team, and whose efforts would be coordinated through the project engineer/manager. The inevitable maintenance scheduling and easy physical access to conduct maintenance in an efficient manner should be considered throughout the design process.

The areas of the most uncertainty, and which therefore carry the greatest risk, should be confronted first. Often secondary steps cannot be fully contemplated until some basic answers or solutions have been found. This may well require some research and development.

Each individual machine designer should have a reasonable knowledge of assembly procedures, the various machining processes, fabricating procedures and additive manufacturing. It would also be beneficial to have some knowledge of the operational characteristics of the manufacturing machines and processes in current use by the target industry. The electrical designers should be experienced with the latest control technology, monitoring systems and related software.

Where the results would meet the criteria, all custom components should be designed to be machined from standard size and readily available materials with the company's available tooling, using the in-house standard fleet of machine tools, and with the processes normally used within the organization. Special processes that require long lead times should be avoided unless the desired results would not otherwise be achievable. Additive manufacturing should be considered for intricate parts; in fact to achieve the necessary geometry for a particular part's required function, additive manufacturing may be the only viable option.

When a machine is designed and engineered for mass production, it is usual to calculate the strengths and lives of most, if not all, of its components to ensure against designing more capacity, life or attributes into the piece of equipment than necessary, which would thereby add to the final costs. At the same time the design must produce a safe and predictable piece of equipment with a life range that meets the decided criteria.

This is also important with custom one-off machines or systems. However, it should be kept in mind that for manufacturing single parts or low quantities, it is easy for the designer to put too much effort into the design of a part while attempting to reduce the cost of one, or just a few components, to achieve a point just above the minimum specified performance requirements. Cost overruns on an accumulation of individual minor components can easily destroy a budget. There can be a difficult balance between minimum design and engineering effort and high quality productive results.

Thorough calculations should be performed for all critical features and/or elements within each component, sub-assembly or assembly. Even though an experienced design engineer may have developed a feel for the relationship of the magnitudes of the components and the forces involved and is able to select the appropriate sizes through visualization, the criteria and rationale should be recorded for the future reference of others in case that particular item or area should fall into question.

All engineering calculations and finite element analyses performed should be recorded, including notes and comments, using current software which can be shared with all on the team. If problems arise in the final design, or even worse, in the completed machine, this would help to more easily locate the error so that the necessary changes can be made. For simple calculations, which are done just on a calculator, or manually, written notes should also be kept, with a sketch where appropriate, showing the procedure and the results.

An important part of a machine design engineer's education is to experience, or to observe first hand: the circuitous route of the materials chase of the buyer; the problems encountered by the machinists and welders; the difficulties experienced by the millwrights in assembling a machine; the crating, loading and logistical nightmares of the shipper; the communications impediments and local resource hurdles faced by the field engineers; and finally the travails of the maintenance crews.

It is folly to release drawings for manufacturing before all of the drawings have been completed and checked. If the timeline is such that it is found that the drawings for some complete assemblies must be released for manufacture before the others have been completed, the project engineer/manager and the designer must be cognizant of the risks that, without the utmost care and foresight, this could lead to great difficulties and expense.

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