CHAPTER 16

Design of Intermittent Motion Mechanisms

PART I—DESIGN PROCEDURE

Now that there is a repertoire of mechanisms to choose from, let us see what steps should be taken to solve specific design problems. Since design is (at least, in part) a creative act it is a little arrogant, perhaps, to attempt to list *a* design procedure. I have known many successful designers whose approach differed considerably from that given below. Nevertheless, this procedure has worked for me, and presumably, it would also work for others.

1. Defining the Primary Problem

Never start to solve a problem until it has been clearly defined. In the case of indexing mechanisms, the primary problem is to produce intermittent motion of a certain type. The following are the basic specifications to this end:

a. Indexing rate required (number of steps per minute)
b. Indexing accuracy required
c. Dwell-motion pattern required
d. Size of load (heavy, medium, or light-duty)
e. Cost situation (an expensive mechanism is acceptable, or medium- or low-cost must be achieved).

2. Defining Secondary Problems

A definition of indexing rate, load, cost, etc., usually determines which major classifications of indexing devices are candidates for a particular design solution. But these specifications alone rarely define the complete problem. Perhaps a size or weight restriction must be placed upon the indexing device. Perhaps special acceleration patterns are needed, or a "mechanical advantage" may be necessary. There may be unusual environmental problems; automatic vending equipment located at the seashore is exposed to a remarkable amount of salt content in the air, for example. In Table 16–1 are listed some of the many factors which the designer may have to consider in selecting a particular intermittent motion mechanism for a specific design.

3. Listing Primary Candidates

Next, consider the various types of intermittent motion mechanisms which have been discussed. Make a mental or written list of those which appear to be the most likely candidates for solving the primary problems (for example, a certain indexing rate, dwell-motion pattern, load capacity, etc.). Table 16–2, at the end of this section, lists the principal features of many of the devices which have been discussed.

The table defines the limits of my own experience with various types of intermittent motion mechanisms. Do not let my knowledge limit you, however, I am sure it would be possible to find some other designs which would be better (or worse) than those indicated here.

Table 16–3 gives detailed information on the input–output motion characteristics of most of

Table 16–1. Design Parameters

SPEED Cycling rate Velocity while in motion SIZE	EASE OF CONTROL Mechanism stands alone Other components required: electronic drive circuits, sensors, hydraulic circuits, etc.	RISK QUOTIENT Does success depend on unknowns? Is this risk really necessary? Is there an alternate solution that involves less risk?
LOAD CAPACITY COST	MOTION CURVES Involve impact Do not involve impact Can be altered by the designer	What can be done to reduce or evaluate the unknowns? EXPECTED PERFORMANCE VERSUS THAT OF THE
ENVIRONMENT Temperature Shock and vibration Vacuum Humidity Salt spray Dust Explosive	SYNCHRONOUS OR ASYNCHRONOUS Designed to operate at a fixed or variable cycling rate. SERVICEABILITY LEGAL REQUIREMENTS	COMPETITION FITTING COMPANY'S ABILITY Does it fit company's present or anticipated skills? In: Design Manufacturing Sales Service
TYPE OF INPUT Continuous Impulse	Accuracy Safety Noise	POWER CONSUMPTION AND EFFICIENCY
DWELL AND MOTION PATTERN Duration of output dwell versus input motion Output displacement versus input displacement Number of dwells per revolution of output Number of output dwells per revolution of input Dwell-motion ratio	MECHANICAL ADVANTAGE Required Useful Not pertinent DEGREE OF CONTROL OVER LOAD Good Fair Poor	UNUSUAL SALES FEATURES REQUIRED CAPACITY TO TOLERATE OVERLOAD OPERATING COSTS WEIGHT
INPUT-OUTPUT Parallel or at right angles	RELIABILITY Will mechanism "always" function?	MANUFACTURE VERSUS PURCHASE
STABILITY OF PERFORMANCE When new When worn	What if it does not? Minor nuisance or catastrophe?	PATENT SITUATION Patentable Interference problems

the mechanisms illustrated in this text, and Table 16–4 lists some of the typical applications for various types of mechanisms. These three tables should be helpful in rapidly selecting possible candidates to solve your design problems.

4. Reviewing the List with the Secondary Problems in Mind

Getting a little deeper into the problem, you should attempt to eliminate any of the primary candidates that fail to meet the important special or secondary requirements for the design. But care must be taken with all of this "eliminating," as the solution to your design problem may very well consist of a slightly modified mechanism. Do not discard a category merely because the obvious members of that branch of the "family" fail to meet one of the requirements. Again, Table 16–2 reflects my own knowledge or experience in this field; do not feel limited or confined by it.

5. Choose the Most Promising Approach

Perhaps only one "solution" will be found by following the previous steps; or you may have found several possibilities. In any event, the time has come for you to select one candidate for further evaluation. This could be either a "pure" mechanism (for example, an external Geneva), or it might be a modified mechanism to satisfy a special situation (for example, a Geneva driven by a four-bar linkage to modify the acceleration pattern). It also may be a combination of two or more types of intermittent motion devices (for example, a Geneva driven by a clutch-brake combination to modify the dwell-motion ratio).

In order to make a selection, you will probably be facing the almost inevitable problem of choosing between apples and hammers. If it were a decision between apples and oranges, it might not be so difficult, for at least they are both pieces of fruit. But in most design situations, there will be two or more possible solutions to a design problem, each having an entirely different set of advantages and disadvantages. One solution, for example, may offer everything you need in the way of reliability, but the mechanism may be a little larger than you plan, and its cost is on the high side. A second solution may offer exceptional speed, a high degree of patent protection, and be easy to make on the company's molding machines. A third solution may be very quiet, remarkably easy to service, and have almost infinite life. Presumably, all three possibilities satisfy your main requirements of indexing speed, load capacity, etc. Your job then is to decide whether low noise level is more desirable than patent protection or unusual reliability, for example. These are the kinds of questions that make a designer yearn for the wisdom of Solomon, for in any event, you must make a selection.

6. Incorporating the Mechanism into Your Design

You have now picked the most promising candidate. Presumably, it is only a component of a larger machine or instrument. Next, you must incorporate it into that larger design. As you do this, you will almost inevitably encounter major or minor problems which you had not anticipated. The size is wrong; or the mechanism requires right-angle shafts and yet your design would be neater if input and output were on parallel shafts; or the device will produce impact and you find you cannot incorporate the large bearings required to tolerate this; etc.

Do not give up on encountering these obstacles, overcome them as well as possible and continue until you strike an obstacle that is definitely insurmountable or until the mechanism is finally successfully incorporated into your design, even though it may be at some sacrifice to your original intentions. This is not recommended simply because I think designers should be stubborn, but because I think a struggle of this kind is often necessary to uncover the *real* problems in a given design situation. At the beginning of your work, you may think you know what the problems are, but it is only after struggling through a complete layout that you really uncover them all.

Do not forget to consider what the performance of the design will be after it has worn a little, by using drawings or plastic cutouts, or models, to study the effects of dimensional changes. Remember also, that intermittent motion places a severe burden on most mechanisms and small dimensional changes can cause significant changes in performance. Try to discover and eliminate all the potential wear points that might affect performance. Also consider all the design parameters listed in Table 16–1 and honestly list the advantages and disadvantages of your new system, now that you have worked it out. This is also a good time to calculate a first, rough cost estimate to compare with your initial estimate; are you in the ball park or did the modifications you were forced to make prove too costly?

7. Reconsidering Other Possible Solutions

Now that you know what the problems really are, reconsider some of the other possible solutions. You may see one that on second thought is quite good and gets around some of the unexpected difficulties encountered while incorporating your first choice into the design. If you make another selection at this point, carry it all the way, also. You may uncover another crop of secondary problems or you may find that it is, indeed, an improvement over your first choice.

8. Warning

Try not to fall into the designer's main trap which is picking a particular solution simply because he thought of it, ego-satisfying though this may be. Pick the best solution for this design even if it happens to be the most common one available; proving that there is at least one designer who can place the welfare of his customer and his company above any desire for self-expression.

9. Design Refinements

If your second solution encounters a new crop of difficulties, you may have to go through the cycle a third time. But eventually you will find one that appears to be an acceptable answer to your main and secondary problems. Go still further; evaluate the "final" design to see if shapes, assemblies, motions, or controls can be simplified even more. Can you expand or reduce function? Can you combine elements? Can you optimize the sequence of operations? Can you improve safety? In other words; act objectively as a design review team, to put those final touches on the device; all of which separates the master designer from the "couldn't care less" school.

It is not to be assumed that your design should be improved indefinitely; nothing will drive a design boss up the wall faster and for better reason. A design that is "too good" is almost as uneconomical as one that is not good enough. The idea is not to let your initial "final" solution rest until you have taken a quick look, at least, at improvements of the type described.

10. Design Review

The time has now come to turn your design over to others for their evaluation. The average newspaper reader can easily detect any bias that the reporter would swear does not exist in his prize article. By the same token, another designer or engineer can spot deficiencies in a design that the designer simply cannot see perhaps because of personal prejudice based on his own experience; because of his desire for self-expression; or because he has just plain overlooked something; etc. Let someone else evaluate your design even if your company does not have a formal design review group. And listen to your critic—debate his conclusions to learn what they are based upon, then modify your design or not, depending upon whether his observations seem valid. But do not be on the defensive until you have really understood what he is saying and have determined whether or not he has actually uncovered a valid problem.

This is also a good time to get another cost estimate. But this time it should be done by someone else, and should be as rigorous as time and information will allow.

By the time you get through all this, you may find that your solution is no longer a solution and you will have to start all over. If so, go back to Steps 3 and 4, or possibly even 1 and 2, and repeat the entire process. Each time through will make you more aware of the total problem and of the advantages and disadvantages of the various solutions in solving that problem. Not infrequently, you will have to throw away all possible common solutions and innovate a new intermittent motion mechanism or system to solve your particular problem. If this were not the case, this book would have been only a fraction of its present length! As long as you are innovating because the design demands it, rather than because your ego demands it, no one can complain. In fact, this is what you are paid for.

Well, we have come a long way and, hopefully, know a great deal more about the mechanics and mechanisms of intermittent motion. This class of mechanism has had a long and important past, as the "Historical Notes" have suggested. I hope each of you will contribute something to its endless and important future.

Design Parameters

Some of the factors which must be considered in selecting a particular intermittent motion mechanism for a particular design are listed in Table 16–1. But the characteristics of the mechanisms we have discussed and a partial listing of their applicability are given in Tables 16–2, 16–3, and 16–4.

Table 16–2. Specifications and Characteristics of Various Types of Intermittent Motion Mechanisms

Type of Mechanism	Cycling Rate (SPM)	Dwell-Motion Ratio (Output-) Time	Relative Load Capacity	Relative Cost	Indexing Precision	Performance Stability		Controls for Mechanisms are:	Degree of Control Over Load
						New	Worn		
Impulse ratchet	1500	High	Low	Low	Moderate	Fair	Fair to poor	Simple	Fair
Cam ratchet	A few hundred	Moderate	Moderate to high	Low to moderate	Moderate	Good	Fair	Simple	Fair to good
Cam	1000	Moderate	Very high	Moderate	High	Excellent	Good	None	Excellent
Instrument Genevas (external)	10,000	Low	Low	Very low	Moderate	Good	Fair	None	Good
Machine Geneva (external)	Hundreds	Low	High	Moderate	Moderate	Excellent	Good	None required	Good
Mutilated gearing	5000	Low to Moderate	Very low	Very low	Moderate	Good	Good	None required	Good
Cycloidal gearing	Few thousand	Very low	Low to moderate	Moderate	Poor to fair	Good	Fair	None required	Excellent
Differential gearing	Few thousand	Very low	High	Moderate to high	Poor to fair	Excellent	Good	Moderate complexity	Excellent
Clock and watch escapements (tuned)	10 to 100	Low	Very low	Low to moderate	Very high	Excellent	Poor	None	Excellent
Machine escapement	10,000	Moderate to high	Low	Low	High	Fair	Fair	Simple	Fair
Inverse escapement	3500	High	Low	Very low	Moderate	Fair	Poor	None required	Fair
Clutch-brake systems	10,000	Moderate to high	Moderate to high	Moderate to high	Low to moderate	Fair	Fair	Complex	Fair to good
Step motor	960,000	Low to high (depending on type)	Low to high (depending on type)	Moderate to high	Moderate	Fair	Poor	Complex	Fair to good
Star wheel	Hundreds to thousands	Moderate	High	Low to moderate	Moderate	Excellent	Good	None required	Good
Roll cam	Thousands	Moderate to high	Moderate to high	Moderate	Moderate	Good	Poor	Moderate complexity	Fair to good

Type of Mechanism	Type of Input to Mechanism	Input Displacement		Output Displacement per Motion	Number of Output Dwells		Designed to Run at Fixed (Synchronous) or Variable (Asynchronous) Rate	Input-Output Parallel or Right Angle
		During Output Dwell	During Output Motion		Per Output Revolution	Per Input Revolution		
Impulse ratchet	Electrical pulses or cam loaded spring	5° to 30°	5° to 30°	1° to 45°	8 to 360	D.A.	Either	D.A.
Cam ratchet	Rotating cam	90° to 300°	60° to 270°	0.1° to 90°	4 to hundreds	1 to 2	Fixed	Parallel
Cam	Rotating shaft	90° to 300°	90° to 270°	90° to 270°	1 to 4	1 to 5	Fixed	Either
Instrument Genevas (external)	Rotating shaft	200° to 270°	160° to 90°	20° to 90°	4 to 8	1 to 2	Fixed	Parallel
Machine Geneva (external)	Rotating shaft	200° to 270°	160° to 90°	20° to 90°	4 to 8	1 to 2	Fixed	Parallel
Mutilated gearing	Rotating shaft	10° to 350°	10° to 350°	10° to many turns	1 to 36	1 to 5	Fixed	Parallel
Cycloidal gearing	Rotating shaft	Few degrees (theoretically 0°)	30° to 360°	30° to nearly 360°	1 to 12	1 to 12	Fixed	Parallel
Differential gearing	Two rotating shafts	0° to many turns	Fractions of a degree to many turns	Fraction of a degree to hundreds of degrees	One to hundreds	One to hundreds	Fixed	Either
Clock and watch escapements (tuned)	Stalled rotating shaft	0°	10° to 30°	10° to 30°	12 to 36	12 to 36	Fixed	Parallel
Machine escapement	Rotating shaft	Few degrees to many turns	Few degrees to many turns	Few degrees to many turns	1 to 100	Fraction of one to 100	Variable	Parallel
Inverse escapement	Rotating shaft or electrical pulses	5° to 300°	5° to 180°	4° to 60°	6 to 90	D.A.	Variable	Parallel
Clutch-brake systems	Rotating shaft	Partial revolution to many revolutions	Partial Revolution to many revolutions	A few degrees to many revolutions	One to hundreds	One to hundreds	Variable	Mostly parallel
Step motor	Electrical pulses	D.A.	D.A.	0.9° to 180°	2 to 400	D.A.	Either	D.A.
Star wheel	Rotating shaft	30° to 300°	60° to 320°	60° to 360°	1 to 8	1 to 3	Fixed	Parallel
Roll cam	Rotating shaft	180° to many turns	30° to many turns	30° to 360°	1 to 12	1 to 5	Variable	Parallel