A Guide To Determining The Required Frame Rate for A High-Speed Digital Camera

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When considering the purchase of a high-speed digital camera to analyze equipment malfunction or study high-speed motion mechanics, the first question to ask is “what frame rates do I need to capture the events that I need to see?” In the case of production machinery, it’s tempting to simply divide the camera frame rate in seconds by the line speed in units per second to obtain the number of frames per unit.

For example, let’s assume that a high-speed digital camera captures images at 250 frames per second (fps). If a liquid filler runs at 500 containers per minute (about 8 units per second) we divide 250 frames/second by 8 units/second to get 31.2 frames per unit. Since 30 frames per unit is usually considered to be enough to adequately analyze an event, a 250 fps high-speed digital camera would appear to be the ideal choice for this application.

The following table illustrates this concept by showing frames per unit at progressive line speeds (in units per minute) for different camera speeds in frames per second.

Frames captured per piece

Frame Rate (fps)	Line Speed (Pieces per Minute)						
	100	200	300	500	1000	1500	2000
1000	600	300	200	120	60	40	30
500	300	150	100	60	30	20	15
250	150	75	50	30	15	10	8
125	75	38	25	15	8	5	4

The Cream Zone numbers show (greater than 30 frames acquired per piece)
the “safe” area where there are reasonable assurances that an event will be effectively captured.

The Tan Zone (11-30 frames per piece) indicates a “marginal” area where successive trials may be necessary to capture an event.

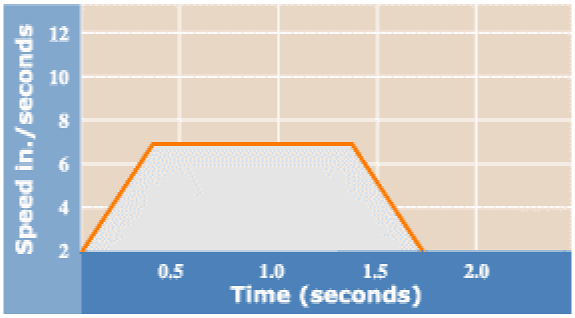
The Orange Zone (10 frames or less) is the “inadequate” area where event capture is not at all certain.

But the real world is usually not quite this simple. The filling system we just described may (and probably does) have multiple heads to fill multiple containers simultaneously. We usually want to study the action of only one of these heads at a time. For simplicity’s sake, let’s assume that this unit has eight heads, so one head fills one container per second. We could probably record this event with a standard camcorder; at the NTSC frame rate of 30 frames per second, we’d have our 30 frames per unit.

The issue, however, is that this "event" as we've defined it is actually comprised of several separate functions. For example, the filling of each container will probably include all of the following actions:

- Load
- Articulate filler
- Fill
- Retract filler
- Unload

We know from experience that load/unload will take about half of the time we have to fill this container. Therefore, the other three functions must all occur in the half second that is left. If we assume that they each take about the same amount of time, then each action will take around 0.16 second. A frame rate of 250 fps will give us 40 frames for each function, so our camera choice still looks pretty good. However, we have not yet considered acceleration and dwell time. Steppers and servomotors don't ramp up and down instantly. A speed vs. time curve for a motor ramp-up/ramp-down can look like this:



Ramp–up or ramp-down can be as little as ¼ of the total interval of 0.16 second, or 0.04 second. If we needed to capture a ramp-up, we'd need 30 frames in 0.04 second, or 750 frames/second! Fortunately, most systems are designed such that functional problems typically don't occur during ramp-up or ramp-down.

What's important is that it would be better to get 30 frames in ¾ of our 0.16 second, or 0.12 second; we will need a camera speed of 250 frames per second to do this. So, in this scenario, the 250 fps high-speed digital camera still seems to be a good choice.

However, it's operating at its upper limit. If you anticipate installing faster production equipment in the future, you might consider a high-speed digital camera with higher frame rates to handle the increased line speeds

Under certain circumstances, the event we wish to observe may be short enough to happen by chance between frames, and will be missed on a single recording. Does this mean we need a faster camera? Not necessarily. What we need is the ability to record an event, observe the frames on the spot, and shoot again if the anomaly was missed. The probability is that in a few "takes", we should have enough information about the problem to make adjustments.

Remember, the goal is not to characterize the problem, but to gain enough data to make adjustments.

Let's now model a production line to determine the camera frame rate necessary for effective analysis and adjustment. For each system on the line, we do the following:

1. If a machine performs multiple simultaneous operations like our fictional liquid filler, we divide its actual line speed in units per second by the number of simultaneous operations to get the speed of each functional unit.

2. Now we can characterize a system in the same way that we did our liquid filler, identifying those discrete operations of interest that we would want to observe in slow motion, remembering the acceleration issues if there are any.

3. By using manufacturer's data, or interpolating from line speed performance, we deduce the total interval for each of these operations of interest. Manufacturer's data, if available, can be highly useful in this exercise.

4. Taking the smallest time interval for an operation of interest on a system, we multiply by 30 frames to obtain the required speed in frames per second. We now have the lowest effective frame rate that will help us maintain this one system.

5. After repeating steps 1-4 for each system on our line, we rank our systems from highest necessary frame rate to lowest. If one of our systems stands out as requiring much higher frame rates than the rest of the line, we may have to examine reliability data for that system and determine whether we need to obtain a camera that will help us with all of our systems, or if we can get by with a less expensive camera that will satisfy the bulk of our needs.