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SIMULATION OF OSCILLATING ARM WIRE MONITOR MECHANICS DRIVEN BY A STEPPER MOTOR

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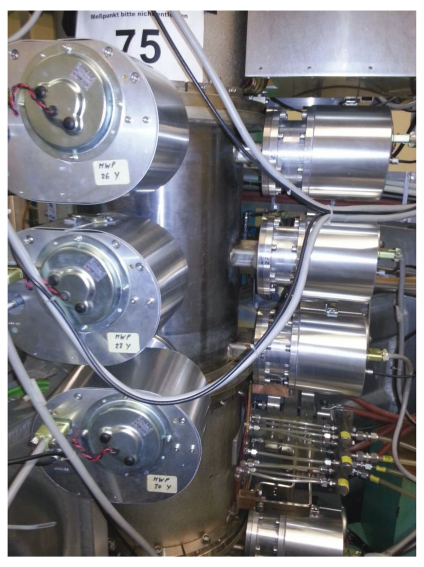
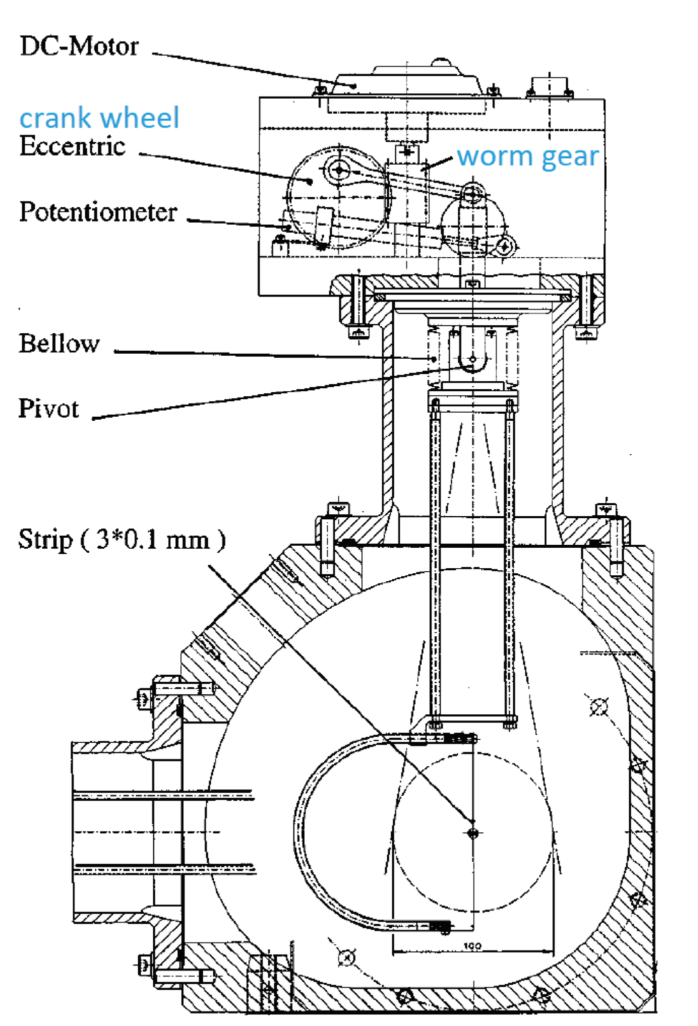
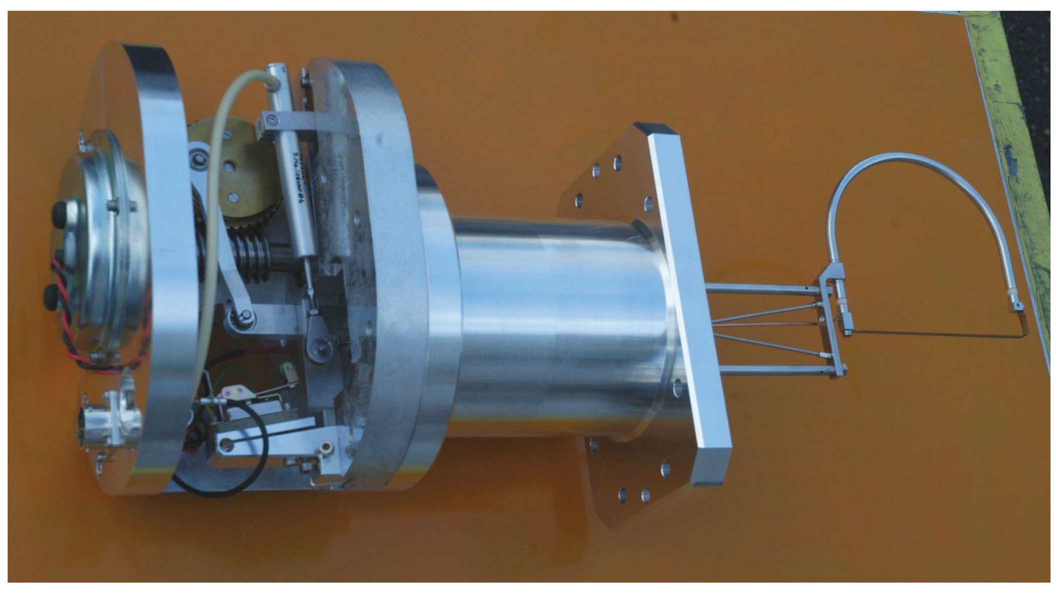
The present oscillating arm wire monitors at HIPA operate with wire speeds of 0.75 m/s. Based on basic dynamic simulations of mechanics and motor, we discuss possible variants of this design using stepper motors in open loop control. The results suggest that 4 m/s can be reached with sufficient position resolution, when using a predefined step sequence customized to the mechanics. This speed should be sufficient to measure the full proton beam current in the injection line.

Present monitors

- In 0.87/72/590 MeV beam lines.
- Oscillating arm driven by DC motor.
- Wire speed 0.75 m/s, not sufficient for full beam current at 0.87 MeV.
- Wire position determined by potentiometer.

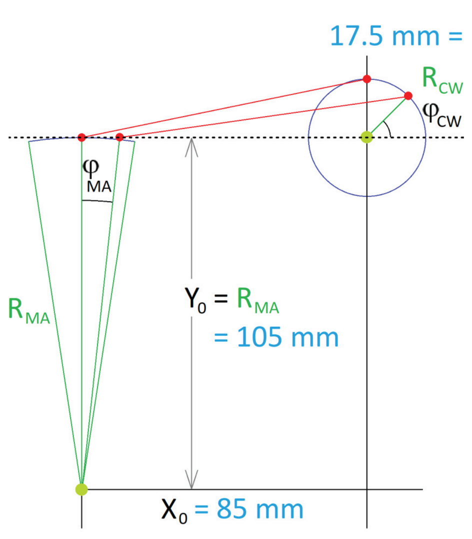


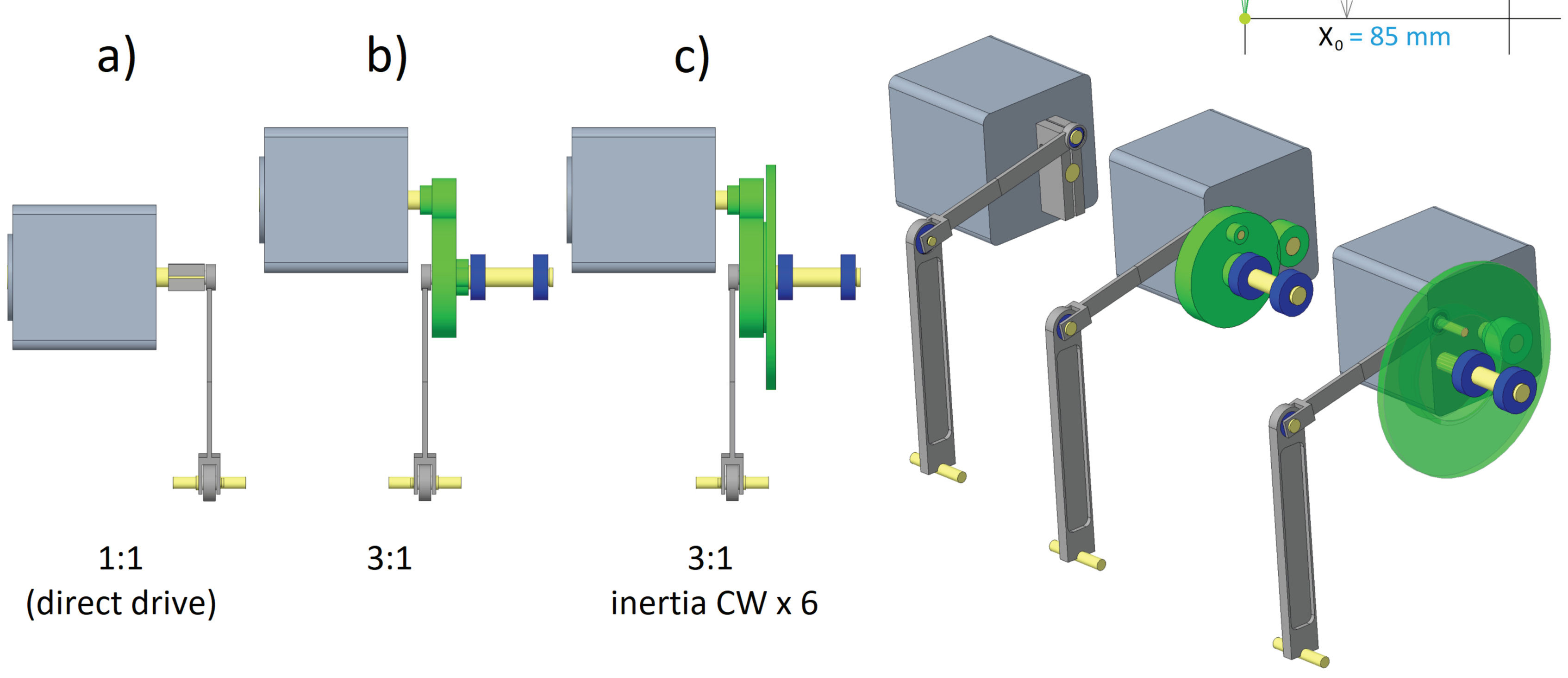




Lower-inertia setups

Three setups simulated, all with same basic dimensions:
1. The present monitor, but with stepper. Worm gear reduction 20:1.
2. Moderately less-inertia. No potentiometer. Spur gear reduction 3:1.
3. Ditto, but gear reduction 1:1 (direct drive).



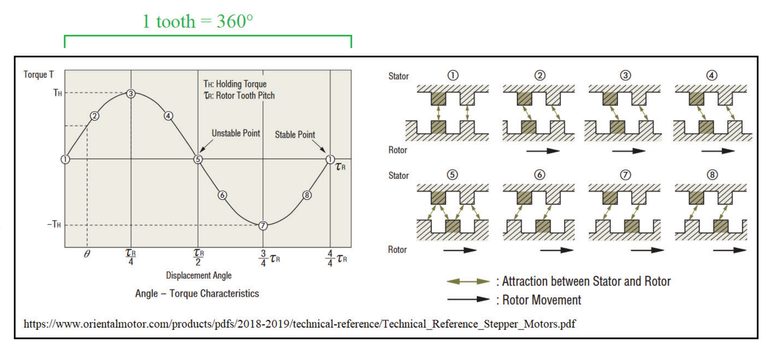


Simulation procedure

The simulation of monitor movement includes:
- Basic geometry and estimated inertias of moving parts.
- Stepper motor speed-dependent pullout-torque characteristic.
- One of the three preset time-dependent 'input characteristics'
  a) rotor angular speed,
  b) rotor angular acceleration,
  c) used fraction of pullout-torque fracD.
- fracD depends on phase difference $\varphi_{tooth} = \varphi_{stat\_cur} - \varphi_{rot}$ between rotor and stator field:
  fracD = sin (φ_{tooth} n_{teeth}), ('cosine potential'),
  with n_{teeth} the number of teeth at the rotor
- Viscous loss due to 'field friction' at different speeds of stator field and rotor.

And the 'disturbing conditions'
- Missing to shift the driver microstep sequence by φ_{tooth}.
- A possible deviation to the assumed pullout-torque characteristic.
- Phase shift due to impedance of motor and cable, microstepping and driver PWM frequency.
- Error of full-step positions due to manufacturing inaccuracies of the teeth of the rotor.
- Loss in worm gear.

The simulation is split into three runs, each done in time steps of 0.2 µs.
1. A 'preset trajectory' is calculated from the 'input characteristic'.
2. The driver microstep sequence is calculated, including 'disturbing conditions'.
3. The 'resulting trajectory' is calculated, including 'disturbing conditions'.

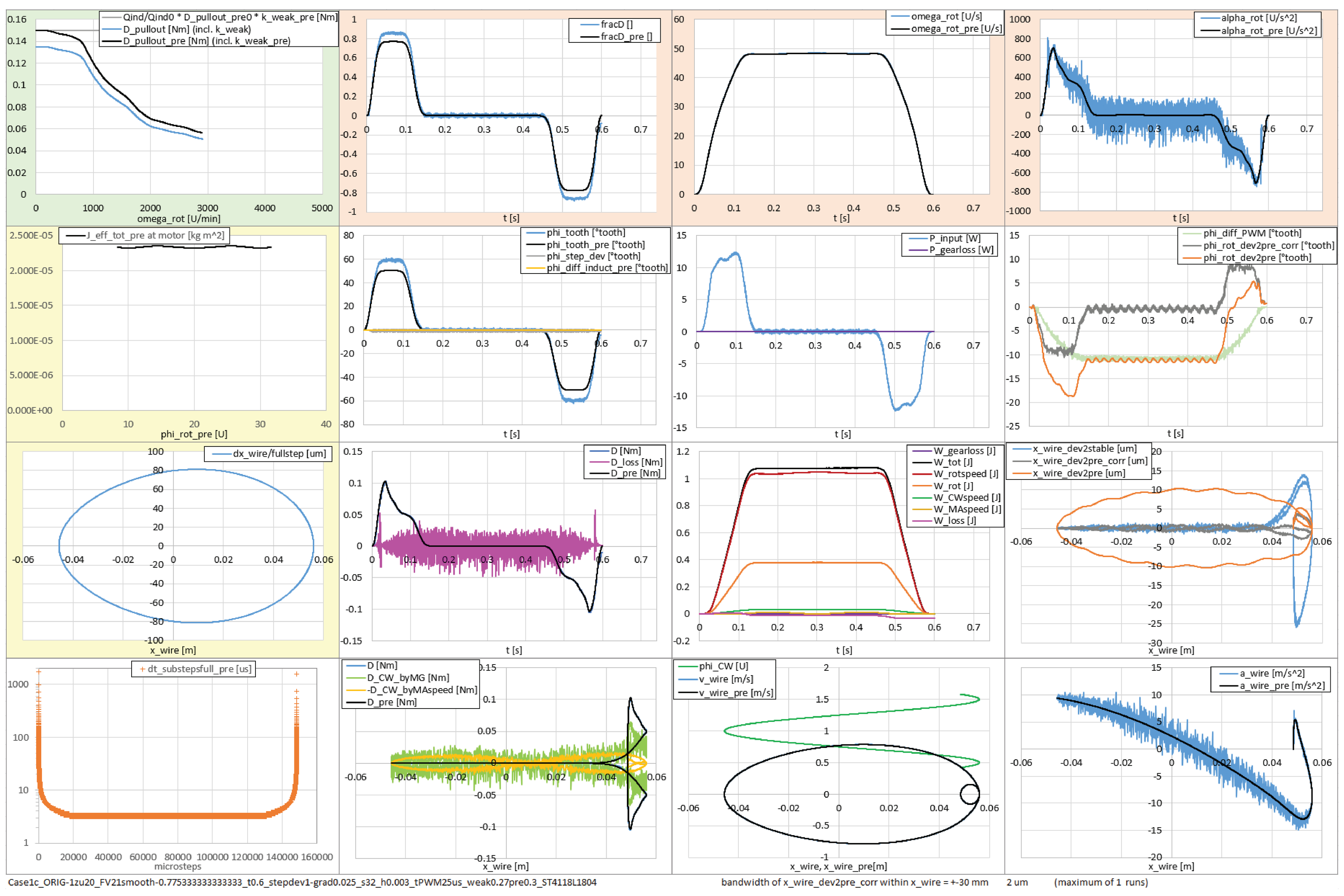


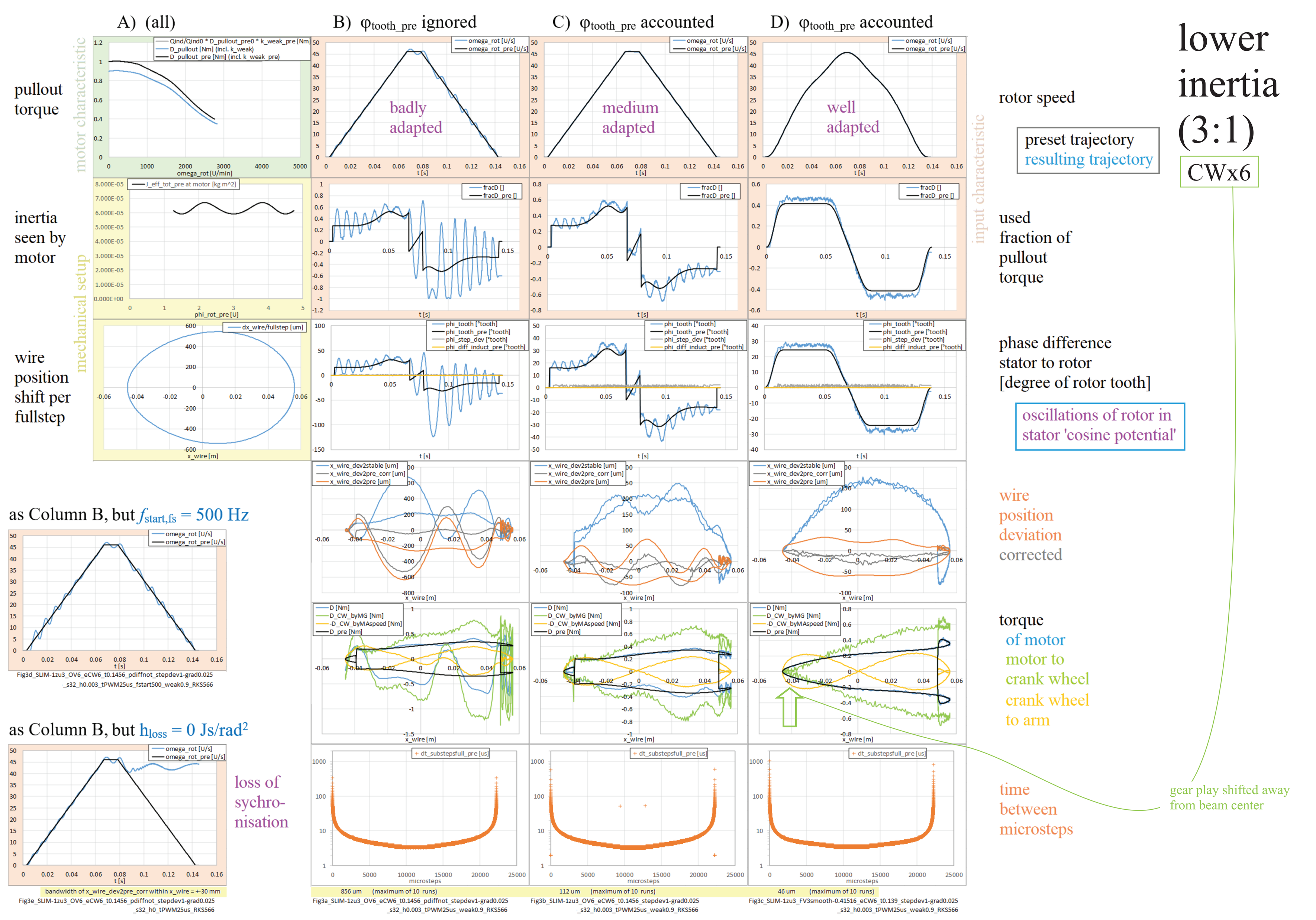
In the 'resulting trajectory', oscillations of the rotor angular position in the 'cosine potential' of the teeth are visible, caused by the 'disturbing conditions' and not well adapted 'input characteristics'.

Angular positions, speeds and kinetic energies of the moving parts and the torques between them are calculated. The error of wire position caused by the motor characteristics and the 'disturbing conditions' is predicted from the difference between 'preset trajectory' and 'resulting trajectory'. For the profile evaluation it is corrected by the predictable part of the effects of PWM and, in case, ignoring φ_{tooth}.

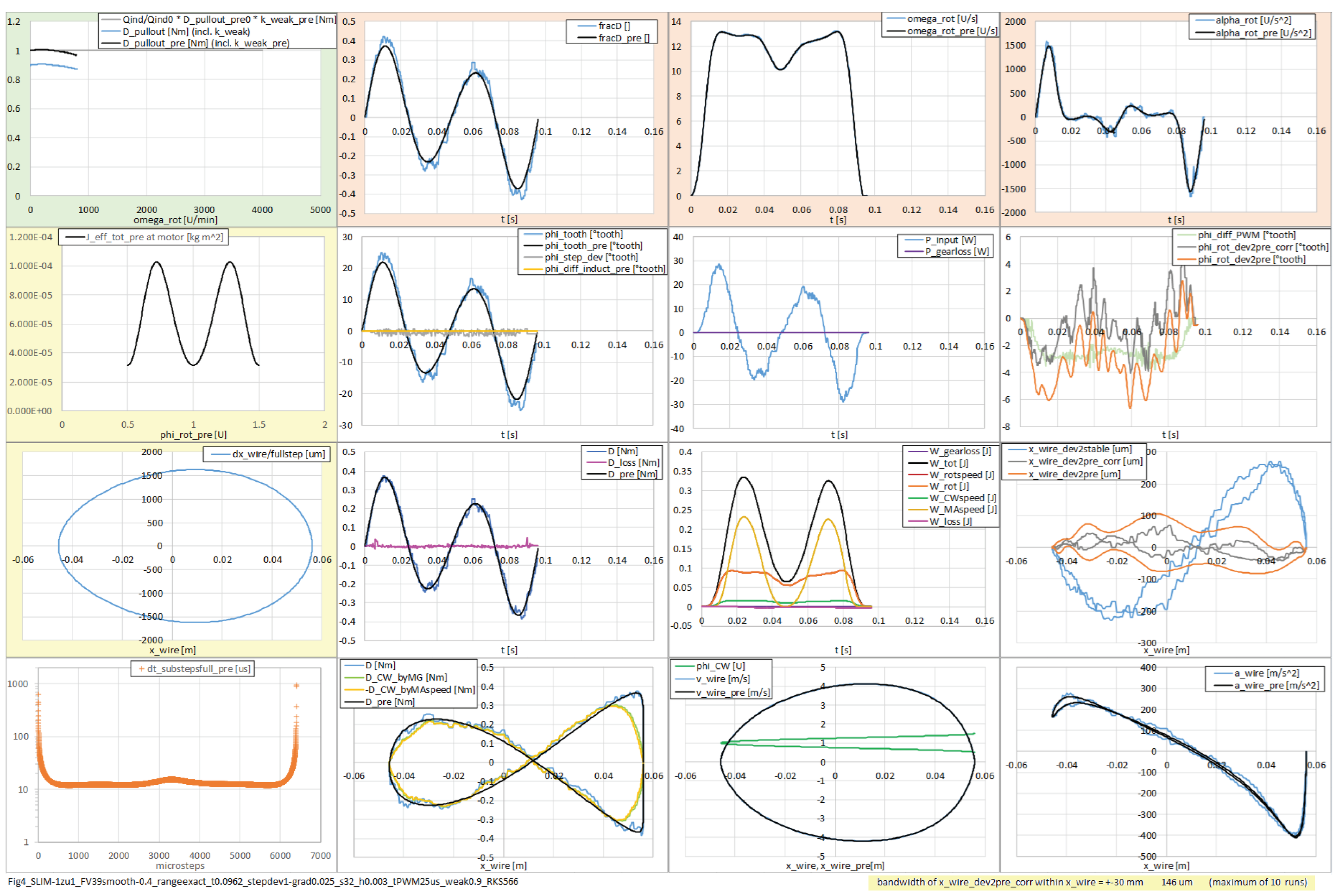
Simulation results

present monitor (20:1)





lower inertia (1:1)



Conclusions

Simulations imply that oscillations in 'cosine potential' of the teeth are reduced by (in this order)
- taking into account φ_{tooth_pre}
- providing a (preferentially smooth) input characteristic, not interfering with the eigenfrequency of oscillations
- the presence of damping h_{loss} >0 Js/rad²
- microstepping at least at lower speeds
- small other disturbing conditions
- reduced motor current, if torque is abundant.

Thereby the accuracy of wire movement is improved, and the used fraction of pullout-torque reduced.

- With an adapted input characteristic, the simulations suggest that 4 m/s are well in reach.
- Electronics able to provide a microstep sequence from a look-up table to the step-direction input of a commercial driver is required for this.
- The predicted accuracy of wire movement, defined as band width of $x_{wire\_dev2pre\_corr}$, is somewhat better at gear ratio 3:1 (~50 µm) than at 1:1 (~150 µm).
- With lower wire velocity the accuracy does not improve. Here, a higher gear ratio can provide better accuracy. With 20:1 ~3 µm is predicted, which is smaller than the effect of the to be expected mechanical play of the mechanism.

- An ultimate limit for maximum wire speed is given by the available motor torque.
- However, oscillations in 'cosine potential' will lead to a loss of synchronisation already at somewhat lower speeds. This is described by the simulation.
- For quantitative predictions, at least, a more precise determination of h_{loss} is required.
- Experimental tests are needed to check the predictions of the simulation. A simple test case can be a motor loaded with an additional inertia.

- A test stand is under preparation to evaluate the performance of monitor setups as the ones discussed here.
- Furthermore, other aspects, as, e.g., the lifetime of the bellows, the stiffness of the MA and wire vibrations will be studied.