for each sea state.

3.2 Approximate Complex-Conjugate Control (ACC). With impedance matching, the optimal control force may be written $F_m^{\mathrm{opt}}(\omega)=-Z_m^{\mathrm{opt}}(\omega)u(\omega)=-Z_i^*(\omega)u(\omega)$, i.e., the optimal machinery impedance Z_m^{opt} equals the complex conjugate of the intrinsic impedance $Z_i(\omega)=R_i(\omega)+iX_i(\omega)$ [35,3]. (The minus sign occurs because of the way we have defined the machinery force, see Eq. (1).) As discussed in Sec. 1, we then need to find a causal approximation $Z_m(s)|_{s=i\omega}$ to the optimal feedback function $Z_m^{\mathrm{opt}}(\omega)$ giving a system as illustrated in Fig. 7.

For a monochromatic wave input of angular frequency ω_k, this optimal force may be written as the time-domain function

$$F_m^{\mathrm{opt}}(t)=(m+m_r(\omega_k))\,\ddot{\eta}(t)-R_i(\omega_k)\,\dot{\eta}(t)+S\,\eta(t) \tag{5}$$

Keeping the same function with constant coefficients (from a properly chosen ω_k) for operation in irregular waves could serve as a simple approximation. We must, however, be careful in order

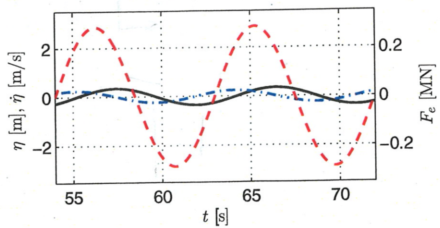

Fig. 6 Regular wave (T=9 s and H=1 m) time series example for the RL strategy. The red dashed curve gives the excitation force F_e, the blue dash-dotted curve gives the velocity $v=\dot{\eta}$, and the fully drawn black curve gives the heave position η.

with optimal values $m_m=-m_c$, $R_m=R_c$, and $S_m=-S$ according to the complex conjugate relation behind Eq. (5). The machinery force is now

$$F_m(s)\equiv -Z_m(s)v(s)=-\frac{m_ms^2+R_ms+S_m}{s}v(s) \tag{10}$$

By cancellation of m_c and S terms, this gives the optimal response velocity

$$v(s)=\frac{F_e(s)}{2R_c} \tag{11}$$

as it should. The force-to-velocity transfer function of the total controlled system becomes

$$H_{v,F_e}=\frac{1}{Z_i(s)+Z_m(s)}=\frac{1}{(m_c-m_m)s^2+(R_c+R_m)s+(S-S_m)} \tag{12}$$

Now to the point: We see that if m_m and S_m are larger than the intrinsic values m_c and S, the coefficients become negative (giving positive poles) and the controlled system will be unstable. Using this as a simplification for the wave energy converter, we may place the poles of the controller such that we are sure not to get positive poles. It can be done by looking at the minimum values for $m+m_r(\omega)$ and S and choosing the controller parameters m_m and S_m with some safety margin, see Fig. 3. We see that stability may be ensured by choosing constant values $m_m\leq 3.72\times 10^5$ kg and $S_m\leq 7.90\times 10^5$ N/m. (We have used the values 3.5×10^5 kg and 7.5×10^5 N/m, respectively.) The parameter R_m may be taken as a parameter to be optimized for each sea state. Figure 8 shows a time series example for the ACC strategy.