Optimal control protocols for the F_1-ATPase motor

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A biomolecular motor composed of protein complexes exchanges energy, matter, and information with its surroundings. Despite being in contact with a fluctuating environment, it performs (on average) a directed motion in accordance with the second law by transducing chemical energy stored in the surrounding environment[1]. Among several biomolecular motors the F_oF_1-ATP synthase has gained much attention due to its high efficiency[2]. It produces ~95% of the cellular ATP (adenosine triphosphate) from ADP (adenosine diphosphate) and P_i (inorganic phosphate). The membrane-embedded F_o-unit utilizes energy from proton flux to rotate the F_1-unit's γ-crankshaft and synthesizes ATP molecules. Since the *γ*-crankshaft rotates as fast as ~350 revolutions per second, it remains a puzzle how F_oF_1 transduces free energy in a highly efficient manner. One possible way to investigate this is to uncover the functional principle of that particular unit where ATP is synthesized, i.e., the F_1-ATPase. To this end, we focus on an isolated F_1-ATPase, which can also be controlled in an experimental setup[3]. We design a control protocol (mimicking F_o operation) by which the F_1 unit's γ-crankshaft can be rotated to synthesize ATP at low dissipation. We follow a near-equilibrium framework to construct a non-trivial designed protocol[4]. Then, we rotate the crankshaft with this designed protocol to compute dissipation. Our analysis reveals that the designed protocol dissipates less energy than a constant velocity protocol for a wide range of protocol durations[5].

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