HEAT LOAD, STRESS AND REACTION FORCE STUDIES OF A POLARIZED POSITRON PRODUCTION TARGET FOR THE FUTURE INTERNATIONAL LINEAR COLLIDER *

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Abstract

The International Linear Collider requires an intense positron beam with yields of about 10^{14} positrons per second. A polarized positron beam can be produced with a helical undulator passed by the accelerated electron beam to create a high power polarized photon beam. The photon beam penetrates a thin titanium-alloy rotating target wheel of 1m diameter with 500 to 2000 rpm rotation speed and produces polarized positrons. The system should run for 1-2 years without failure. A break down can occur due to the huge heat load in a short time (<1ms). The target design must keep the resulting thermo-mechanical stress below the yield strength and the fatigue limit of the material. FEM ANSYS simulations are used to evaluate the thermo-mechanical stress as well as the vibrations at the bearings of the rotating system. Results are presented with the goal to optimize the target wheel design parameters for a long lifetime.

UNDULATOR BASED ILC SOURCE FOR POLARIZED POSITRON PROCUCTION

The ILC will provide e^+e^- collisions in the energy range from 220 to 500GeV, upgradable to 1TeV [1]. The positron beam will be produced using the e^- beam which passes a superconducting helical undulator to generate circularly polarized photons [2]. The polarized photons hit a Titanium-alloy target located 400m downstream the undulator to produce polarized positrons [3]. Depending on the undulator parameters, a polarization of about 30% can be achieved for the positron beam which can be enhanced up to 50% using a photon collimator [4]. The corresponding intensity reduction of the positron beam has to be compensated by a longer undulator section.

In order to distribute the heat load of the photon beam a rotating Ti-alloy wheel up to 2000 rpm with a radius of r=0.5m is proposed. The rim velocity is v=100m/s. The thickness of the rim is $0.4X_0 = 1.48$cm for Ti [1].

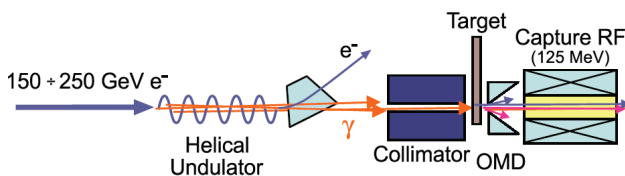Figure 1: Scheme of the undulator based ILC positron source.

HEAT LOAD IN THE TARGET WHEEL

Fig.2 shows the energy loss calculated with FLUKA Monte Carlo code [5] for the parameter set 500GeV (high luminosity) and a collimated photon beam with r=1mm which corresponds to 50% positron polarization. The photon beam hits the target rim with 2625 bunches in a train of 961μs duration and 5Hz repetition rate. A photon beam power of about 80kW is required to achieve a positron beam with 50% polarization and a bunch charge of 3.2nC. About 4kW is deposited in the target. The instantaneous temperature rise in the rotation target is roughly 120K per bunch train since the heat load is distributed on the rotating wheel rim. Only after 7.4s the beam hits the same place again.

Stress Induced Evolution in the Target Wheel by Temperature

The ANSYS Multiphysics FEM software [6] can perform analyses of static and dynamical stress evolutions induced by time dependent heat loads. The temperature input file is calculated by FLUKA [5]. Fig. 3a shows the average temperature distribution on the target wheel with water cooling for a 250GeV electron drive beam.
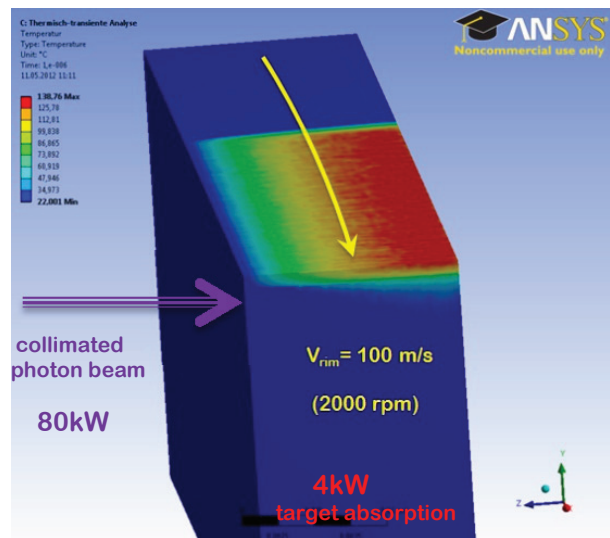

Figure 2: Temperature distribution in the rotating ILC Ti-alloy target wheel (T_{max}=138.8°C). The temperature input file for the ANSYS [6] software is calculated by FLUKA [5].
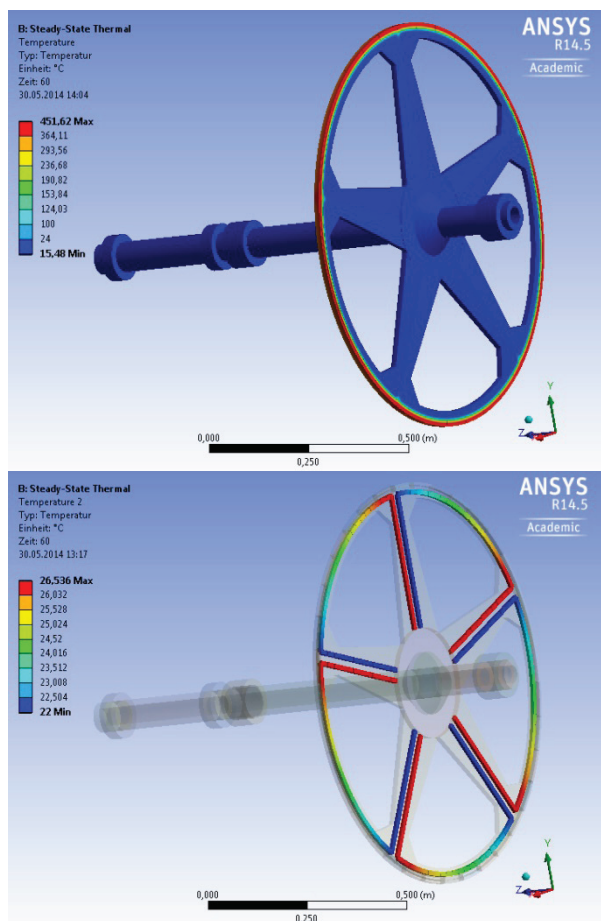
Figure 3: a) Average temperature distribution on the target wheel with cooling. b) Temperature of the cooling water inside the cooling channels.
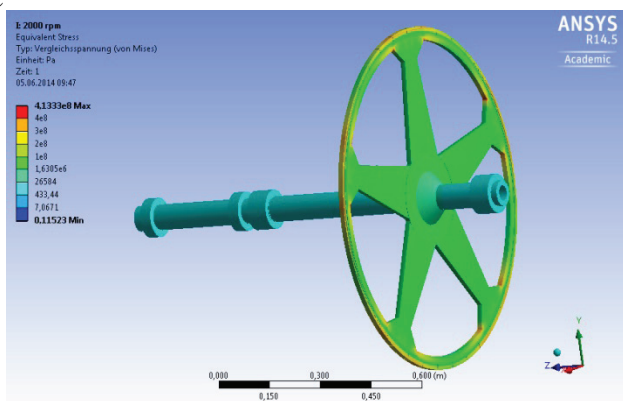

Figure 4: The pulsed beam induces deformation at the rim and generates a perpendicular force at the wheel bearings due to gyroscopic dynamics.

The average temperature at the wheel rim is defined by the cooling power. Fig. 3b shows the temperature evolution of the cooling water inside the cooling channels with a flow of 0.1l/s. These results include the heat load due to eddy currents: The target rim moves through the fringe field of the pulsed flux concentrator (OMD). For a

field of 0.5T at the target, the additional heat load amounts to 4kW for continuous operation [9, 10, 11]. Taking into account a duty cycle of 1/1000 (1ms), the heat load due to eddy currents is only 4W per bunch train distributed to a length of about 10cm of the spinning rim. However, this consideration neglects residual currents from the pulsed magnetic field and – more important - the intermittent force on the target shaft and bearings resulting from the pulsed braking power of the eddy currents.

In addition to the temperature rise the centrifugal force is important. Considering only a 1m-Ti-rim of 1.4cm thickness and 3cm height, the centrifugal force creates a stress of 45MPa. In Fig.4 the stress in the wheel due to temperature loads and centrifugal force is shown. It is easy to see that for the wheel the transition from the spokes to the rim has to be carefully designed to avoid peak stresses in these regions and to reduce the maximal stresses at the rim.

Fatigue Stress Limit for the Wheel Alloy

In order to avoid material failure of the target wheel, the temperature and stress distributions have to be below ultimate limits. To afford a long-term operation, the acceptable peak stress values as well as the fatigue limits of the material may not be exceeded. The fatigue limit is for Ti6Al4V 350MPa to 500MPa depending on the degree of notching [7, 8]. Here, the maximal total stress value achieve 340MPa and is below the fatigue stress limit.

TARGET WHEEL REACTION FORCES AND TORQUE WITH ANSYS [6]

Outside the vacuum chamber two conventional bearings support the wheel shaft. Ferromagnetic fluid sealing the vacuum chamber feed trough of the rotating shaft. Inside the vacuum chamber a magnetic bearing supports the wheel. Preliminary tests of a fluid sealed wheel shows that perpendicular forces can heat up the oil to high temperatures which could leads to a breakdown of the O-rings [11, 12]. This heat generation could be reduced by using an additional magnetic bearing inside the vacuum chamber which provides a better alignment of the shaft [12, 13]. The test of the target wheel was successful at 2000 rpm and ran for 1 month with a total torque of 3.5Nm.

Fig.5 presents a sketch of the wheel with beam induced reaction forces and the resulting torques due to gyroscopic dynamics. The beam impact zone has a volume of roughly 2cm^3 and a mass of 9g (Titanium). Due to the temperature rise it expands by a maximum value of 15μm at the exit side. Following the ANSYS results, this corresponds to an acceleration of 800m/s^2. So the resulting force in z-direction can be estimated to 7.2N. In Fig.6 the results for the torques and reaction forces at 2000rpm are shown. Due to the adverse lever arm the highest values occur at the fluid seal and the second conventional bearing. The beam induced action of about
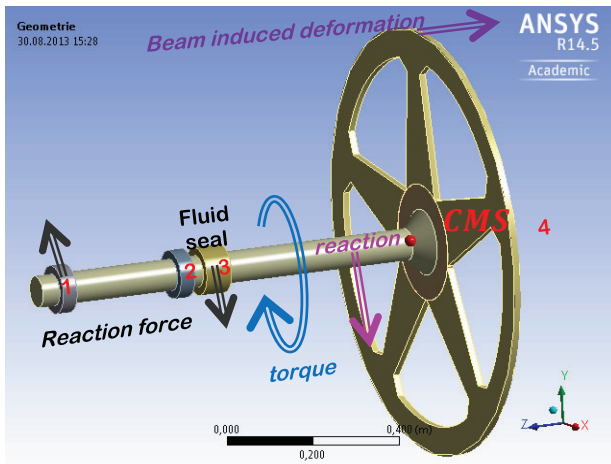
Figure 5: The dynamical beam induced deformation at the rim generates a perpendicular force at the wheel bearings due to gyroscopic dynamics. The four bearings are here numbered with first conventional bearing (1), second conventional bearing (2), fluid seal (3) and magnetic bearing (4) inside the vacuum chamber.
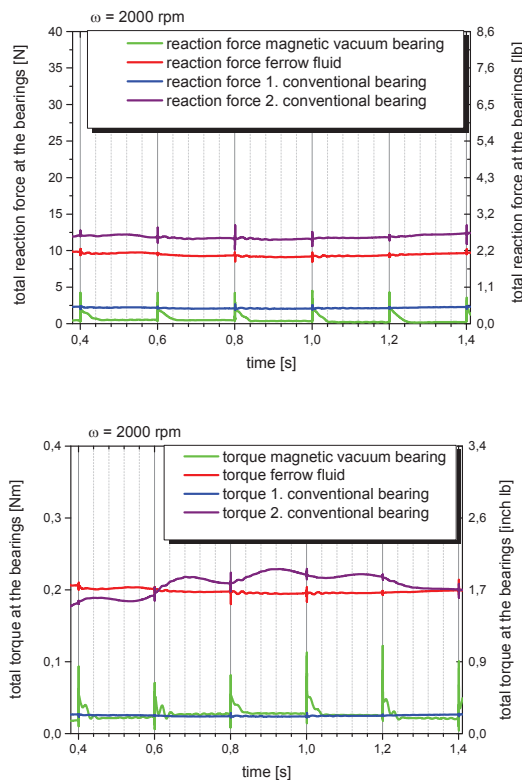

Figure 6: Reaction force and torque induced by the heat loads and the gyroscopic dynamics at 2000rpm at the four bearings.

10^{-4}Nm at the rim causes a spike with an axial torque of 0.1Nm at the magnetic bearing. At the fluid seal and the second conventional bearing spikes of roughly 0.03Nm occur. The torque at the first conventional bearing is negligible. Thus, the calculated additional dynamic reaction forces and torques at the bearings induced by the beam and eddy currents are at quite safely levels for the bearings compared with the experimentally measured values of 3.5Nm [11].

SUMMARY

The calculated stresses and reaction forces at the wheel and the bearings caused by the beam impact and eddy currents from the magnetic field of the OMD are at save levels. The maximal axial torque of about 0.2Nm is low compared to the value of about 3.5Nm measured in the experiment with a sufficiently smooth rotating wheel [11]. In order to decrease the static stress at the connection of the wheel rim and the spokes, a design with smooth transition is needed. The values of stress caused by frequently instantaneous temperature rise are below the fatigue limit which is important to afford the required target lifetime.

OUTLOOK

The results of these simulations yield a step forward in the target wheel design which is a challenge. This concerns in particular the fluid vacuum seal and the bearings at high rotation speed (see [11, 12, 13]). The simulation of electromagnetic dynamics is planned for future studies in order to evaluate the additional braking force induced by eddy currents from the pulsed flux concentrator.

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