Executive Summary

ES.1 The Problem

Conventional rotor balancing techniques for high volume production of rotating machinery often have limitations:

1. They are time consuming, because the balancing process is discontinuous and iterative.

2. Balance correction is usually carried out while the rotor is stationary and not under conditions resembling actual operation.

3. Mass removal methods and some mass addition methods generate particulate debris.

4. Mass redistribution methods are too complex and bulky to incorporate into small, low cost rotors.

Balancing approaches that do so while the rotor spins are too complex and expensive to be applied to rotors manufactured in high volumes.

There is consequently a need to push the limits of current balancing practice to improve productivity and balance quality.

ES.2 The Solution

We conceived and demonstrated feasibility of the Stanford MASs Redistribution Balancing Method (SMASR), which accomplishes balance correction while the rotor spins without physical contact, by means of deformable elements which relocate three discrete masses through local heating under the action of centrifugal forces.

The basic principle of the SMASR balancing method is:

1. Controlled amounts of incremental deformation are produced in metallic elements by exploiting the elevated temperature dependence of plastic flow**:**

    a. Under normal operation, centrifugally induced stresses in the element produce only elastic (recoverable) strain.

    b. During the balancing process, elevated temperature achieved by controlled, radiative pulse heating allow the prevailing stresses to plastically deform the element thus resulting in a permanent mass shift.

A physical embodiment of the SMASR balance assembly is schematically shown in Figure ES.1 and the entire system in Figure ES.2.

Three mass lobes connect to a common base plate via short, thin-walled, prismatic elements subject to torsion. A conical reflector located in the bore of each strain element allows radiant energy impinging on the bore from an external source to heat a portion of the strain element. Synchronously rotating optics allow a stationary source to deliver radiant energy to each strain element as the rotor spins. A control system using unbalance information adjusts the phase of synchronously rotating optics and the duration and magnitude of the heating pulse to carry out prescribed mass shifts necessary to correct the unbalance.

Methods for heating and deformation on a component level have been confirmed by experiment, and quantitative design of a SMASR balance assembly was carried out for a 5¼ in. rigid disk drive to correct up to approximately 20 gm-mm of unbalance at 3600 RPM.

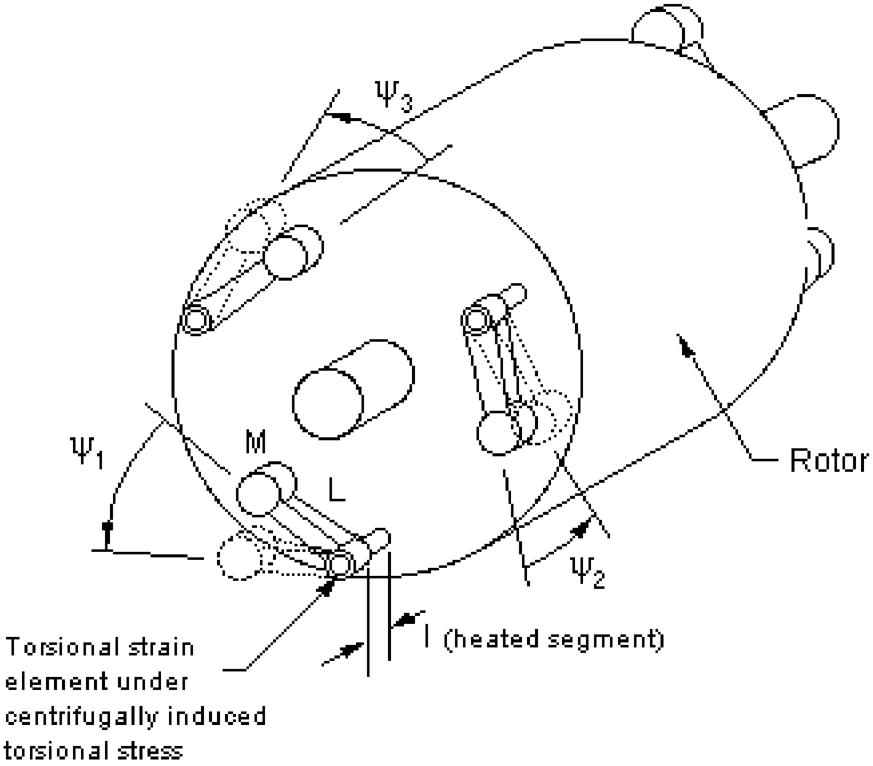

Figure ES.1 Schematic diagram showing SMASR torsional strain element units attached to a rotor. Controlled torsional deformation of specified strain elements allows the redistribution of discrete masses to correct rotor unbalance.

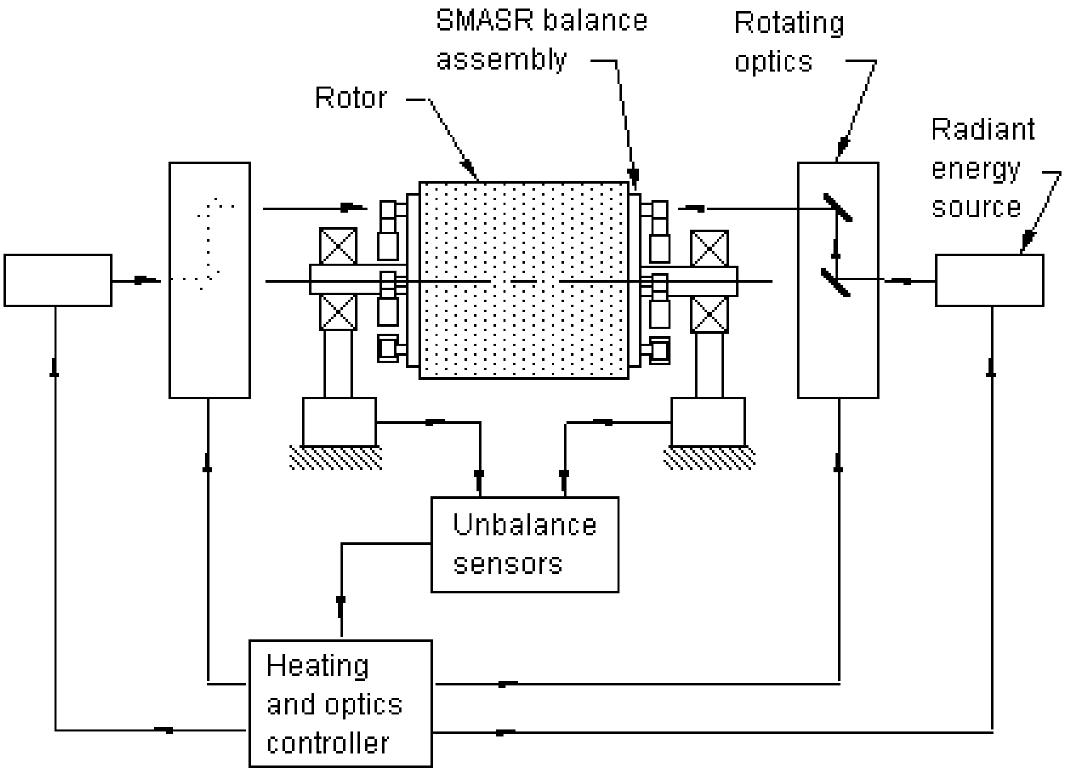

Figure ES.2 Schematic diagram showing the proposed SMASR balancing system. Sensors measure unbalance and feed data to a controller. The controller directs radiant energy sources and synchronously rotating optical units to heat specified strain elements mounted in two balancing planes on the rotor, causing them to deform predetermined amounts necessary to correct the unbalance.

ES.3 The Essential Elements of the SMASR Balancing Method

Figure ES.3 summarizes the essential elements of the SMASR balancing method:

1. The design of the balance assembly

2. The exploitation of the elevated temperature time-dependent deformation behavior of metallic materials under stress

3. The non-contact heating method

4. The mass shifting procedure

ES.4 Summary of Key Accomplishments in Light of the Essential Elements Underlying SMASR

1. <u>The design of the balance assembly</u>

We designed, modeled, and tested a practical torsional strain element and mass assembly with the following features (see Chapter 4):

1). Compact geometry

2). Capable of large torsional strain without failure

3). Can be heated rapidly without contact using a radiative heat source

We demonstrated the adequacy of 304 stainless steel as the strain element material (see Chapter 4).

We developed a general design procedure for applying SMASR to any rigid rotor (see Chapter 7).

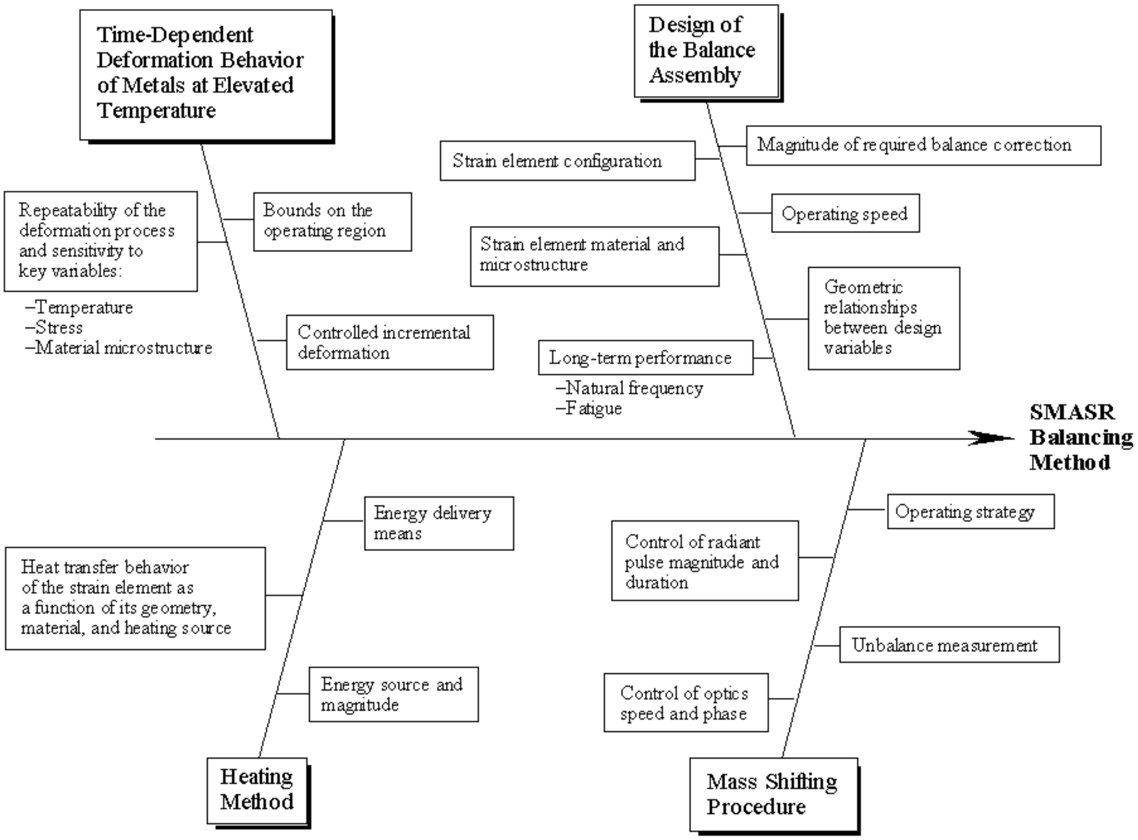

Figure 5 Essential elements of the SMASR balancing method

2. <u>The exploitation of the elevated temperature, time-dependent deformation behavior of metallic materials under constant stress</u>

We demonstrated the ability to produce controlled incremental deformation of a stressed element by pulse heating through analysis and experiment (see Chapters 5 and 6).

We investigated the repeatability of the deformation process and its sensitivity to the key variables: temperature, stress, and material microstructure by analysis and experiment (see Chapters 5 and 6).

We bounded a feasible operating region in terms of temperature, stress, and material microstructure in which the SMASR balancing method can be carried out (see Chapter 7).

3. <u>The heating method</u>

We devised and experimentally demonstrated a means to uniformly and rapidly heat a thin-walled tubular strain element using a conical internal reflector. The reflector causes the incoming energy to heat the inner surface of the strain element by radiation, and the bulk of the strain element is thence heated by conduction (see Chapters 4, 5 and 6).

We analyzed and identified the important parameters controlling the element's heat transfer behavior (see Chapter 5).

We established quantitative requirements for radiant sources and confirmed that synchronously rotating delivery optics are quite feasible based upon prior art in the literature (see Chapter 4).

4. The mass shifting procedure

We devised an operating strategy for the balancing process (see Chapter 7).

ES.5 Next Steps for Further Research

The most important areas to address in future research on the SMASR balancing method are:

1. The demonstration of a full-system rotating prototype, including development of:
    a. The optical heating system
    b. The control system
2. The refinement of the balance assembly for improved manufacturability
3. The search for superior materials for the strain element
4. The demonstration of the long-term reliability of the strain element
5. The extension of SMASR to flexible rotor balancing