Naval Surface Warfare Center
Dahlgren Division

Concept For Improving Cook-off Performance of Propellants and Explosives

Presented by

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WELCOME

Insensitive Munitions and Energetic Materials Technology Symposium

Indianapolis, Indiana

October 2022

The Leader in Warfare Systems Development and Integration

Introduction and Background

A concept for improving the cook-off performance of munitions is explained. The performance improvements could be preventing reactions, delaying the time to reactions, and/or and reducing the violence of reactions.

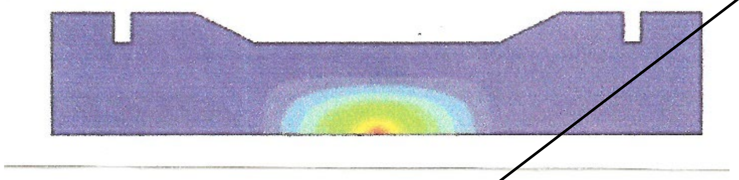
A reactive cook-off occurs due to an instability that occurs when heat is evolved from exothermal decomposition, and the heat produced exceeds the ability of the explosive material to conduct it away from the reaction zone. The rate of reaction increases exponentially as temperature increases. The decomposition rate and release rate of thermal energy rate is completely unstable and a violent reaction results.

The concept involves introducing heat conduction paths that wick the heat out of interior points of the energetic material. Reactions could be prevented, or at least made to occur near the outer surface of the munition, where there is less confinement and much less violence.

Modeling Results for Cook-off of PBX at Two Heating Rates

Slow Heating,

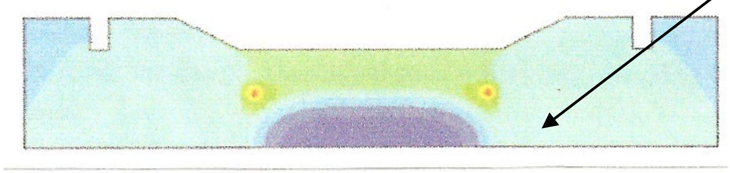
3.3° C / hr



Slow heating
Bulk temperature elevates to the point where the heat from the thermal decomposition cannot get out fast enough and leads to an explosion. The centerline is the place where heat has the most trouble diffusing out fast enough to prevent a thermal runaway.

Fast Heating,

3.3° C / min



Faster heating
Bulk temperature elevates to the point where the heat from the thermal decomposition cannot get out fast enough at some interior point well away from the centerline, and leads to an explosion at some point well away from the center.

The faster the heating, the closer to the surface the reaction is, and the less violent the explosion.

J.C. Gois et. al, Cook-off Test Models and Results, Laboratory of Energetics and Detonics, University of Coimbra, Portugal

Example of Solid Propellant Rocket Motor Insensitive Munitions, Testing and Simulation

Heat trapped in dome of rocket motor leads to reaction ahead of rest of propellant

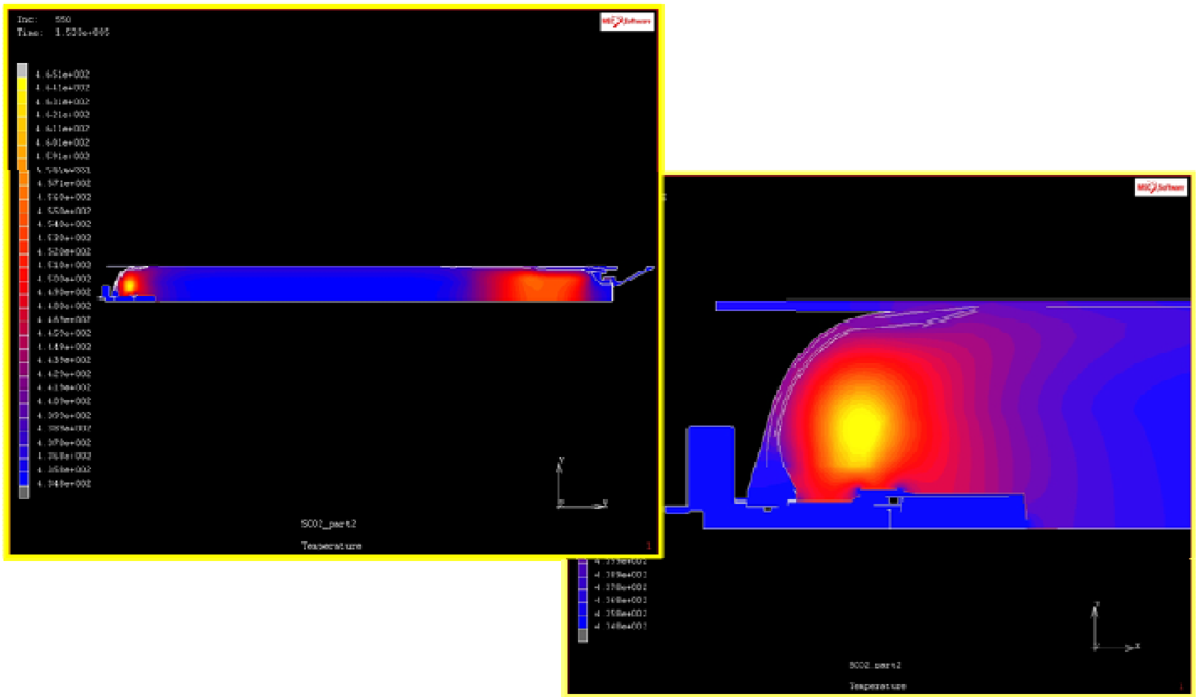


Figure 11: FE-temperature distribution of the HBR-motor just before the SH-reaction

Dr. A. Weigand*, G. Unterhuber*,
K. Kupzik**, Dr. T. Eich***, B. Bucher***

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Solid Propellant Rocket Motor Insensitive Munitions, Testing and Simulation

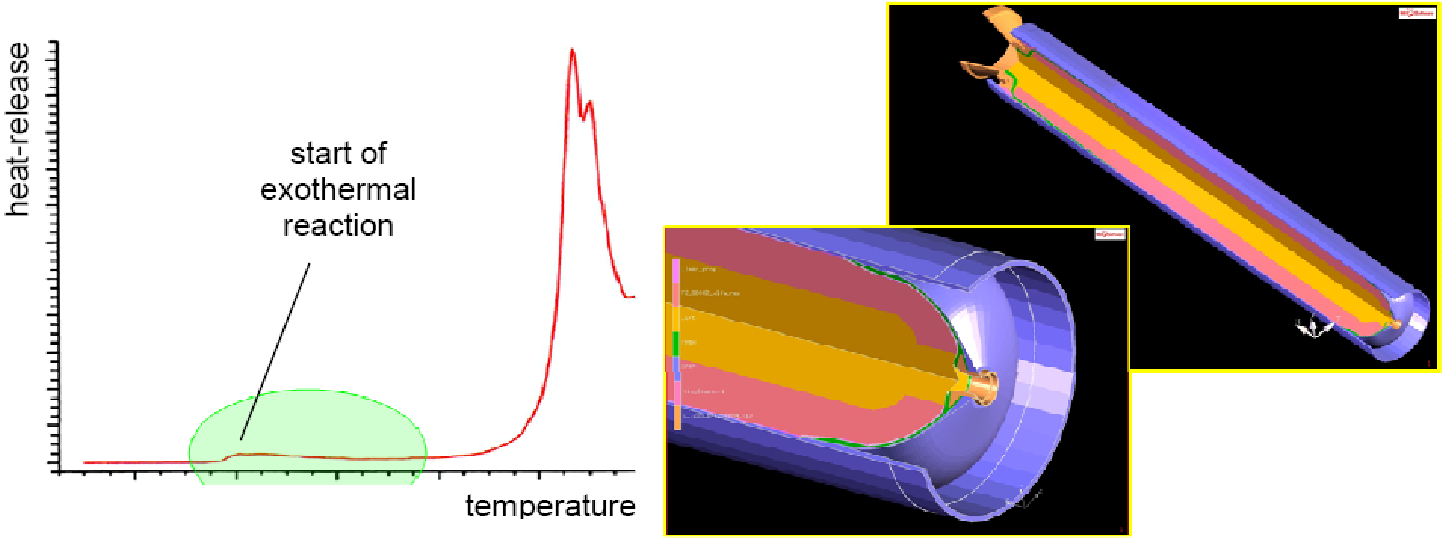

Figure 10: Results of DSC calorimetry and FE-model of the HBR motor.

Figure 11 shows the computed temperature distribution in the HBR rocket-motor and the air in the bore just before the SH-reaction. The computation is two-dimensional and used a measured 3.3℃/h oven-temperature profile as bounda ry condition. The results indicate the formation of a hot spot in the dome region close to the bore surface. At that location, the SH-reaction would actually start. While the temperature of the hot-spot is only 10K higher than that of the hot region in the rear of the motor, the residual part of the grain remains at oven-temperature level. The physical meaning of the hot-spot location is that this is the thermally best insulated region in the motor with the least amount of heat loss through conduction.

Dr. A. Weigand*, G. Unterhuber*,
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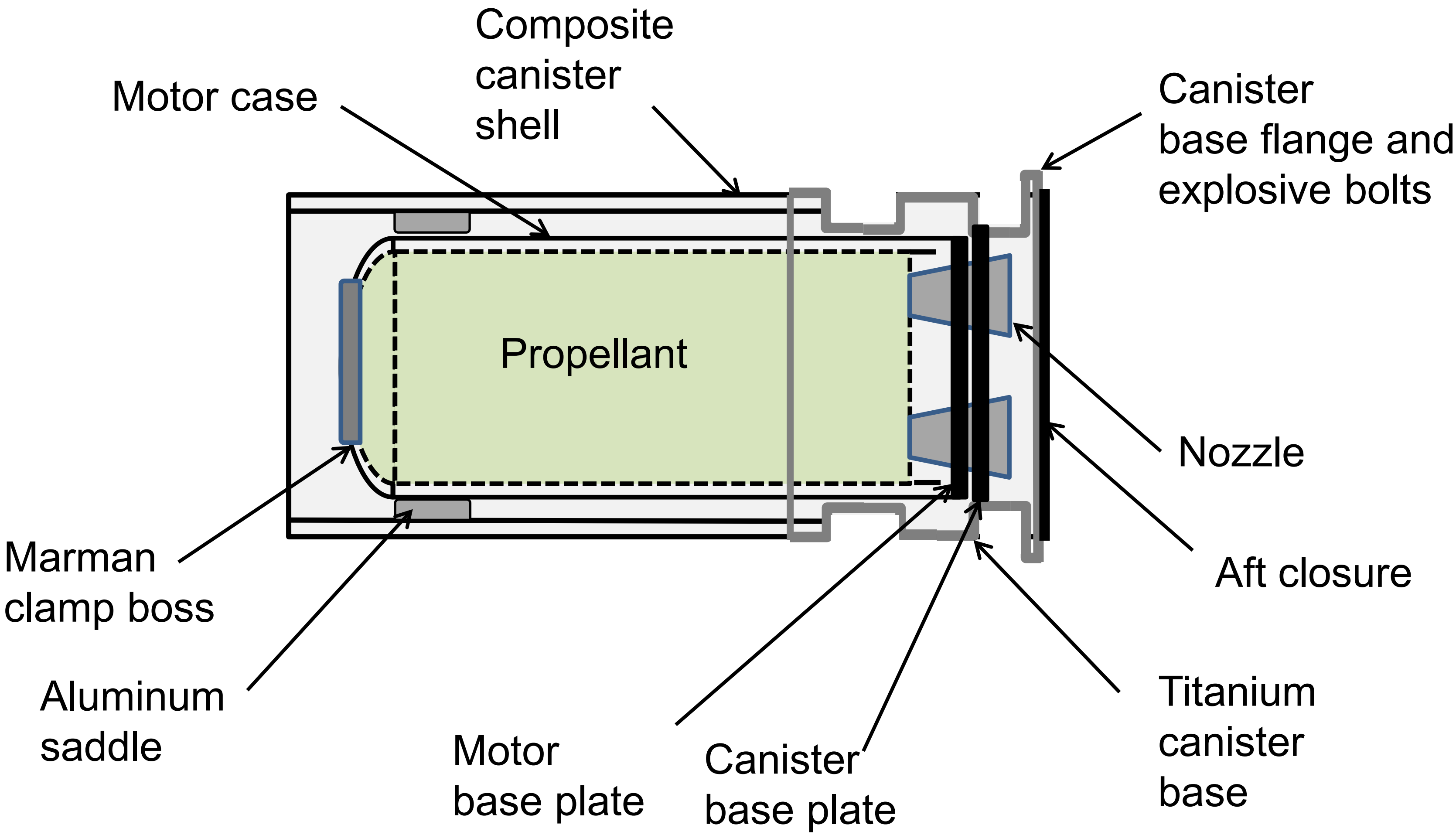
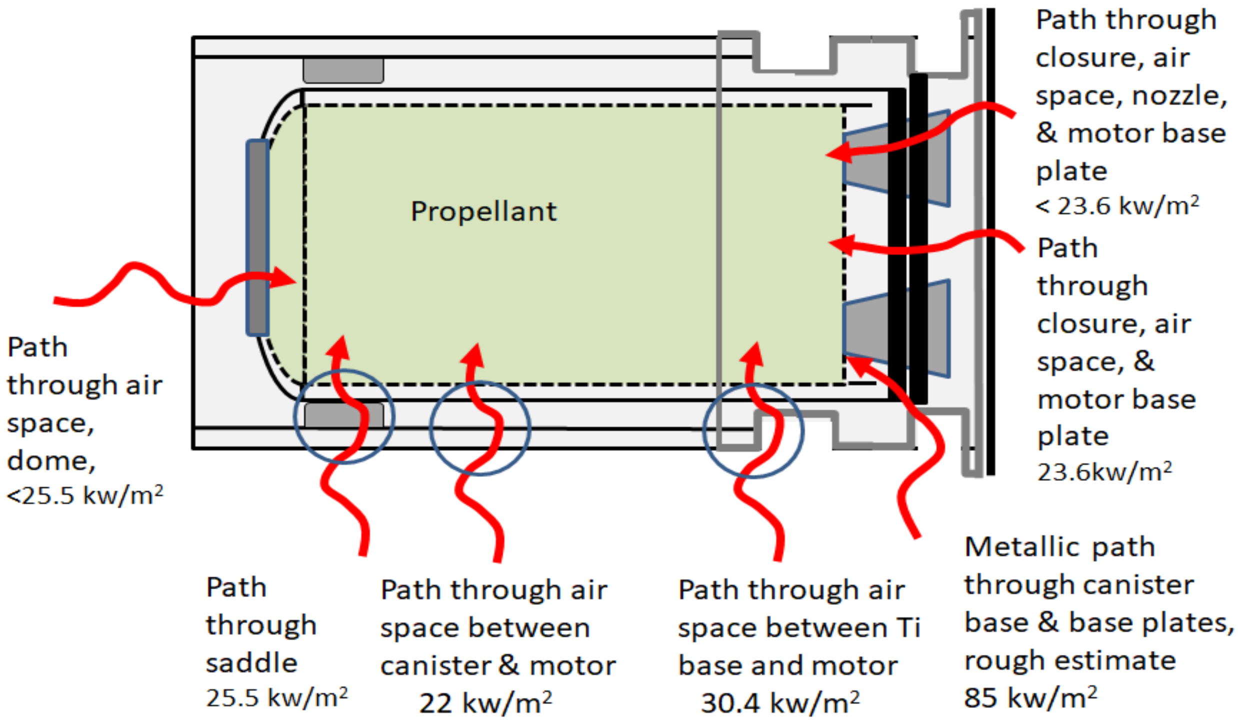
Heat Flows Along Several Thermal Paths Into a Rocket Motor Propellant in a Fast Cook-Off Casualty and Test

The new concept is to find a way to get unwanted heat out of the rocket motor.



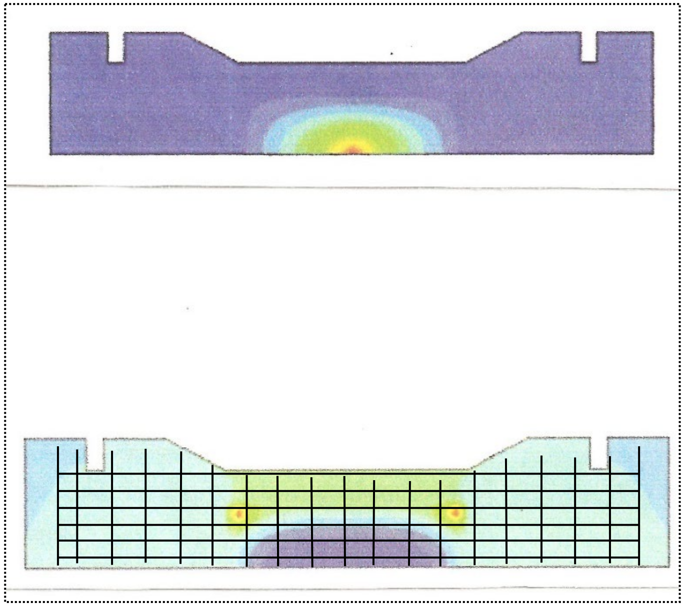
Thermal Paths to Propellant Leading to a Cook-Off Event

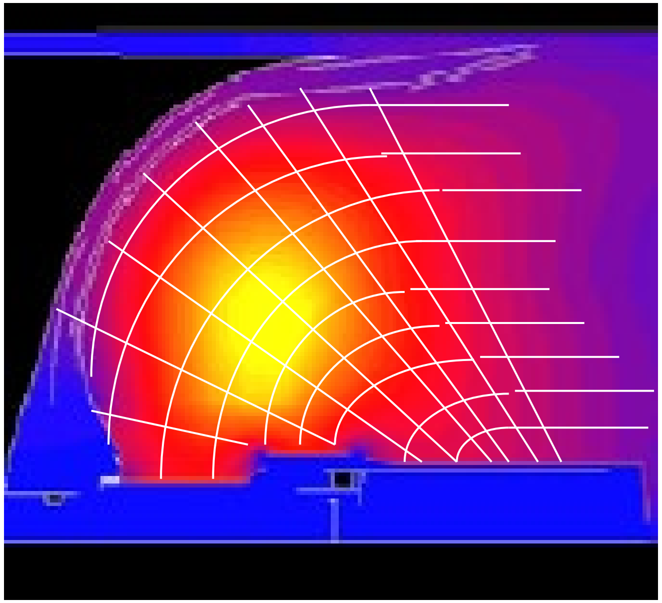


Heat fluxes into the propellant range from 22 to 85 kW/m^2 for fast cook-off in realistic scenario

Mitigation Concept - Meshes

Uniform and lowest possible temperature maintained





Wire meshes imbedded in energetic material conduct heat away from hot spots to outer surface where reactions would be less severe. Wires terminate short of outer surface to assure minimum confinement of reaction.

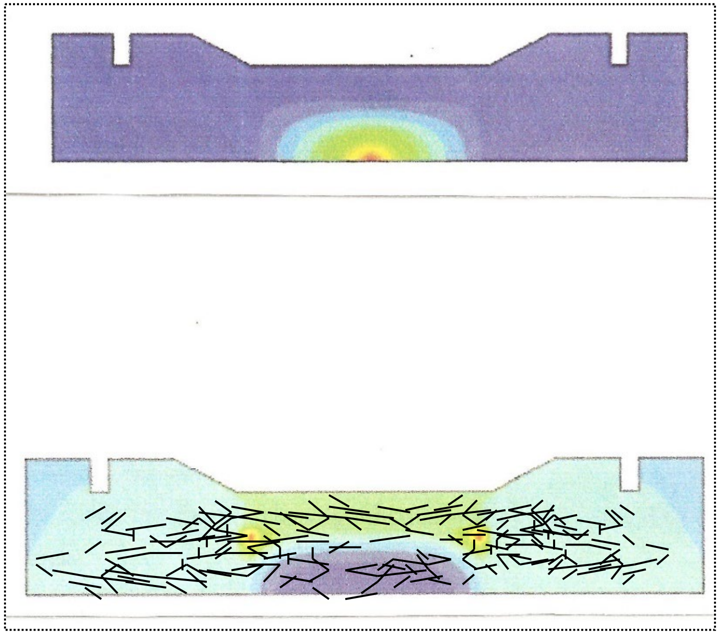
Aluminum and magnesium wires have high thermal diffusivity and can be used as a reactant so there is no weight penalty.

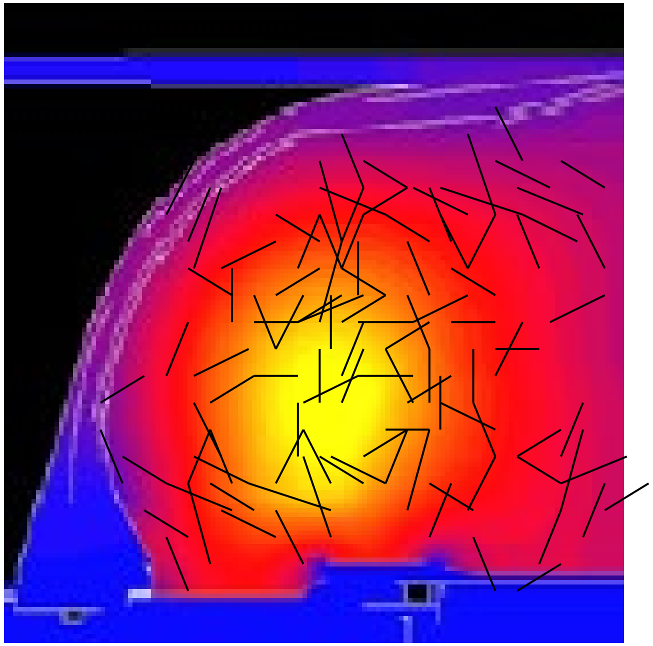
Grids produced in 3-D metal printers could simplify manufacturing and create precise flow paths and variable diameter conductors.

3-D Finite element models could be used to design grids that follow isotherms and heat flux vector fields for optimum performance.

Mitigation Concept - Fibers

1. Use fiber meshes to diffuse incoming heat throughout energetic material to allow uniform and lowest possible temperature.

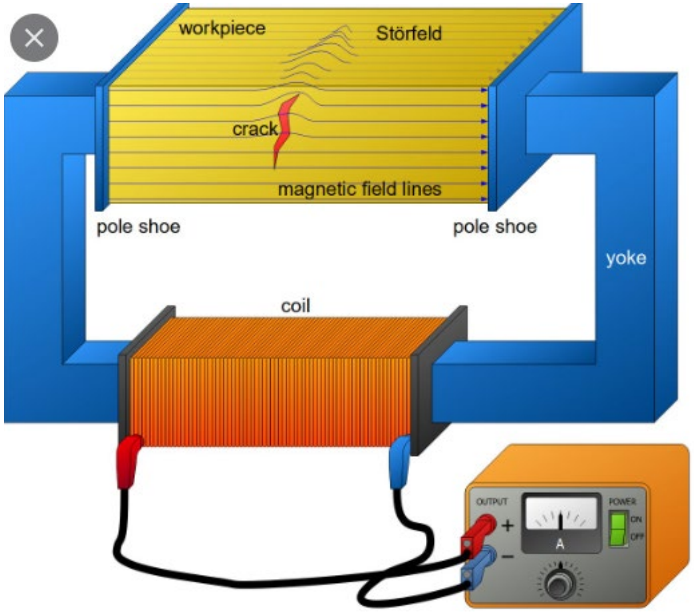


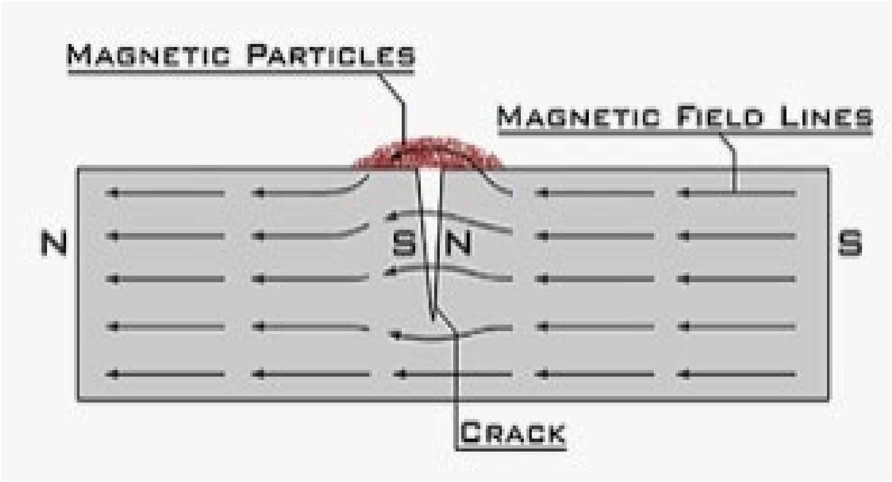


2. Fibers imbedded in energetic material conduct heat away from hot spots.
3. Aluminum and magnesium fibers have high conductivity and can be used as a reactant, and strengthen material for shock and vibration.
4. Synthetic and stainless steel fibers are routinely used to reinforce materials, e.g. concrete.
5. Fibers could be aligned in a magnetic field while casting propellant or explosives.

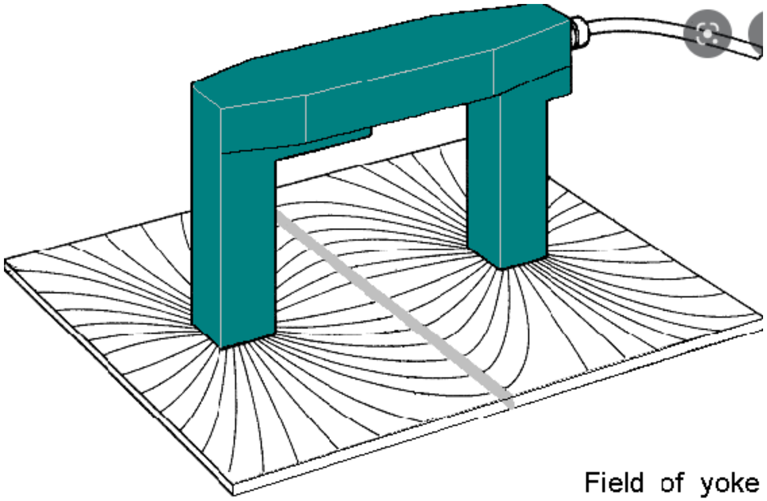
Magnetic Particle Testing

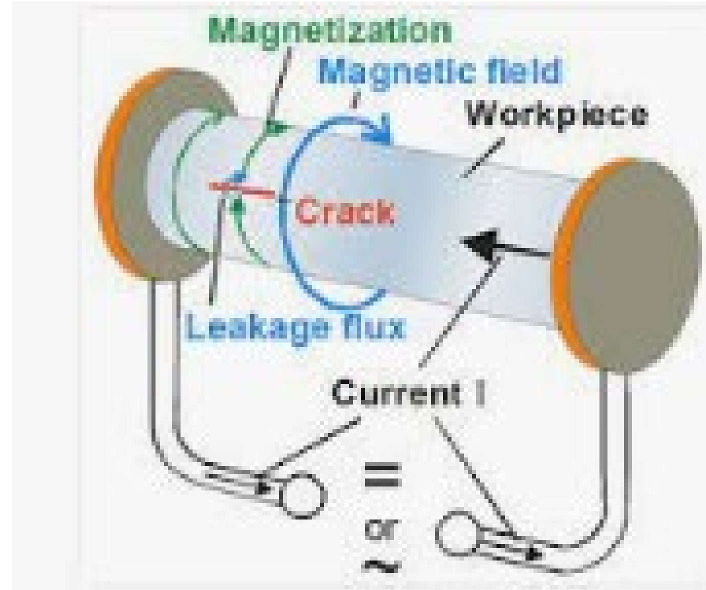
Idea comes from author's personal use of magnetic particle (MT NDT) of gun parts inspection, and use of stainless steel fibers to achieve super high strength (>10ksi) concrete structures



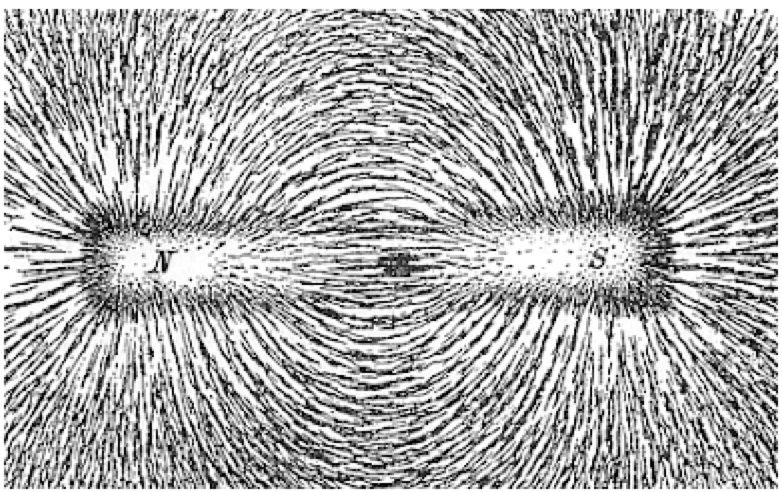


Ordinary MT technique

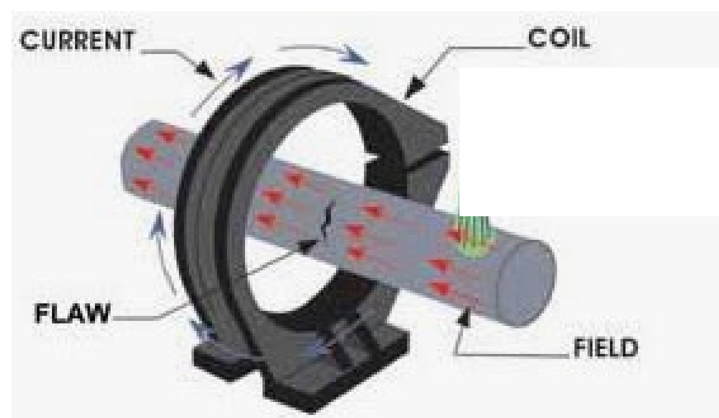




Axial technique



Iron particles align with magnetic field on bottom side of plate



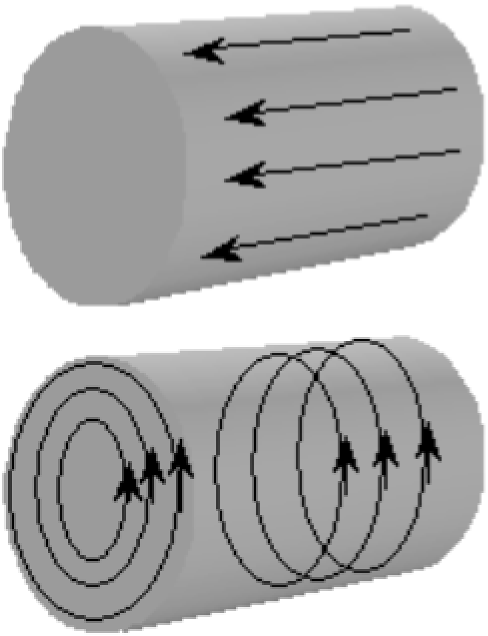
Circumferential technique

A Look Into The Math

Magnetized particles can be aligned in any direction by superposition of a longitudinal field with a circular field

A **longitudinal magnetic field** has magnetic lines of force that run parallel to the long axis of the part. Longitudinal magnetization of a component can be accomplished using the longitudinal field set up by a coil or solenoid. It can also be accomplished using permanent magnets or electromagnets.

A **circular magnetic field** has magnetic lines of force that run circumferentially around the perimeter of a part. A circular magnetic field is induced in an article by either passing current through the component or by passing current through a conductor surrounded by the component.

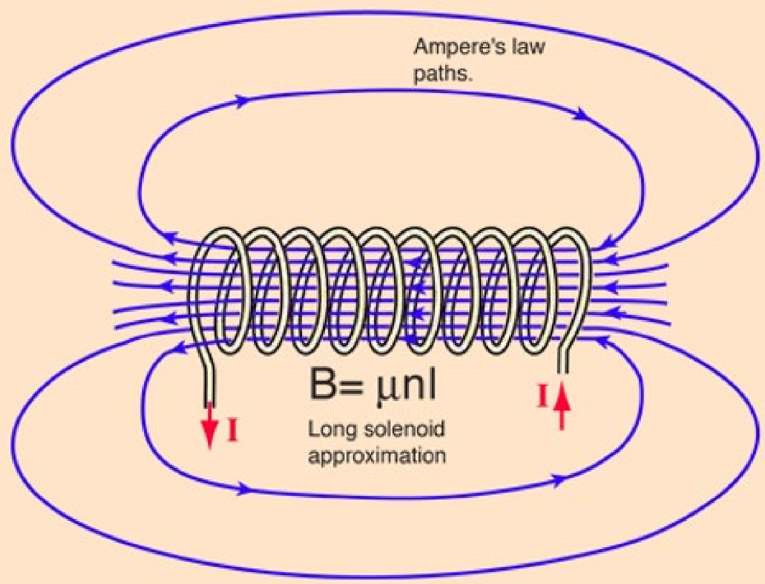


A computer field theory solver can compute path lines along which the particles will align themselves

Solenoidal fields are fundamental to electricity and magnetism

Partial differential equations theory allows superposition (adding) of solutions in different coordinate systems to solve complex problems

A long straight coil of wire can be used to generate a nearly uniform magnetic field similar to that of a bar magnet. Such coils, called solenoids, have an enormous number of practical applications. The field can be greatly strengthened by the addition of an iron core. Such cores are typical in electromagnets.



The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weaker and the lines representing the magnetic field are further apart.

In the above expression for the magnetic field B, n = N/L is the number of turns per unit length, sometimes called the "turns density". The magnetic field B is proportional to the current I in the coil. The expression is an idealization to an infinite length solenoid, but provides a good approximation to the field of a long solenoid.

Journal of Magnetism and Magnetic Materials 522 (2021) 167538

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Thermal and dipolar interaction effect on the relaxation in a linear chain of magnetic nanoparticles

We will use these new analysis methods and results to align the conductive fibers

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A R T I C L E I N F O

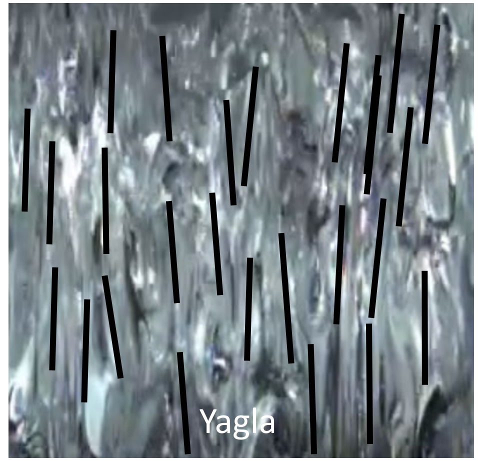
Keywords:
Dipolar interaction
Magnetic relaxation
Thermal effect
Random anisotropy

A B S T R A C T

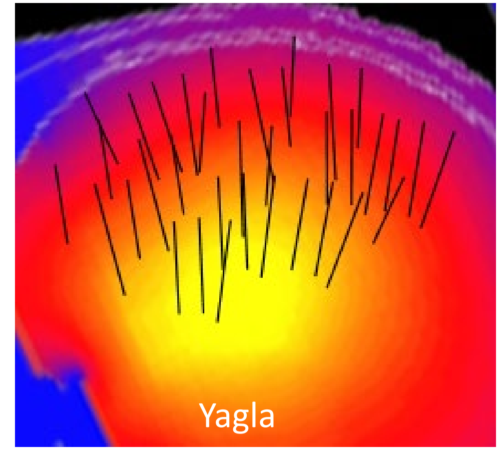
We perform computer simulations to study the relaxation in a one-dimensional chain of dipolar interacting magnetic nanoparticles (MNPs). Using the two-level approximation of the energy barrier, we perform kinetic Monte Carlo simulations to probe the relaxation mechanism as a function of dipolar interaction strength and temperature. The anisotropy axes of the MNPs are assumed to have random orientations. At high temperatures, the magnetization decay curve is exponential for weak dipolar interactions. It is found that dipolar interactions slow down the magnetic relaxation and increase the effective Néel relaxation time τ_N, which is affected by thermal fluctuations. In the weak dipolar limit, there is a perfect agreement between simulated and analytically evaluated values of τ_N for a wide range of temperatures. Microscopic analyses such as magnetic moments correlations and dynamic domain formation also suggest an increase in ferromagnetic coupling with an increase in dipolar interaction strength or decrease in thermal fluctuations. We believe that the concepts presented in this work are relevant in the context of applications such as data storage, digital data processing, and magnetic hyperthermia, in which the linear chain of MNPs are pervasive.

Possible Fiber Alignment In Acoustic Field

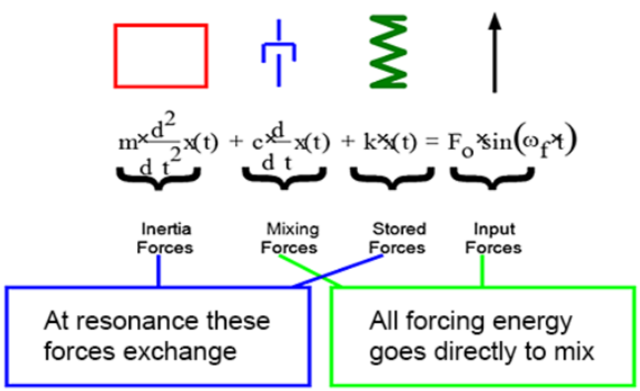
Propellant strands in alignment



Long fibers in alignment



Alignment in radial acoustic field



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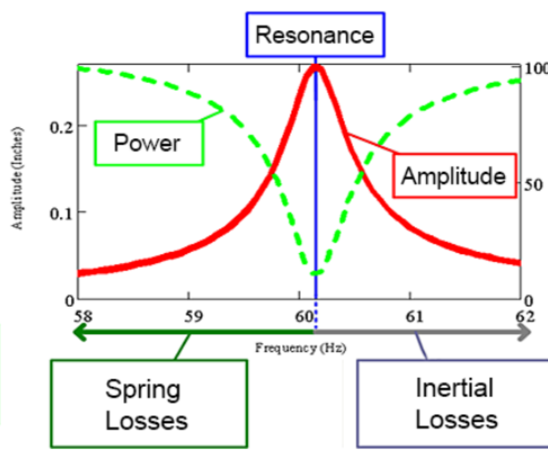
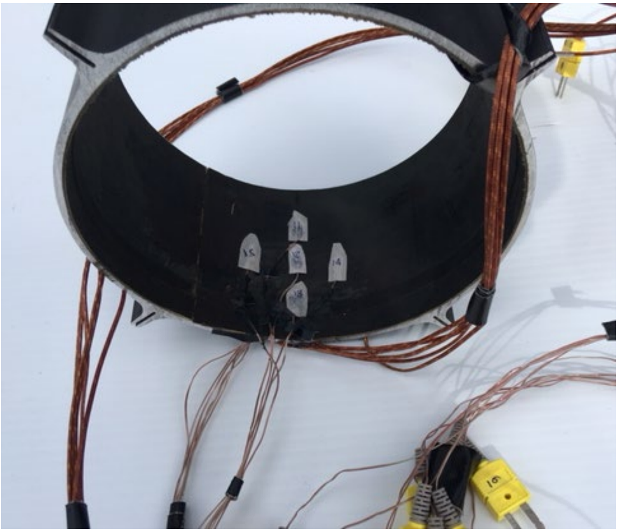


25-100 Hz Frequency
12mm Displacement
100 g Acceletation

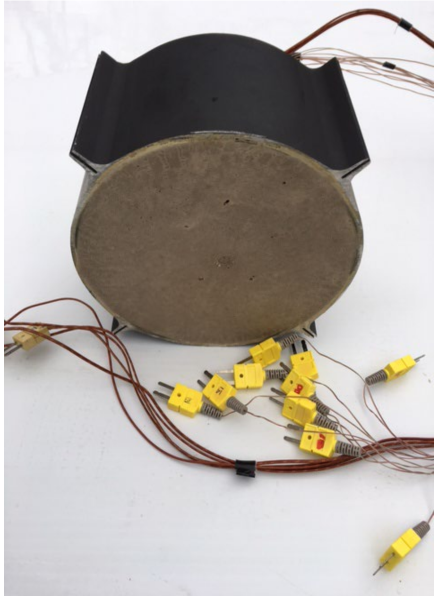
Resodyn Corp

Test Method: Buildup Used for Fast-Heating Test of Rocket Motor

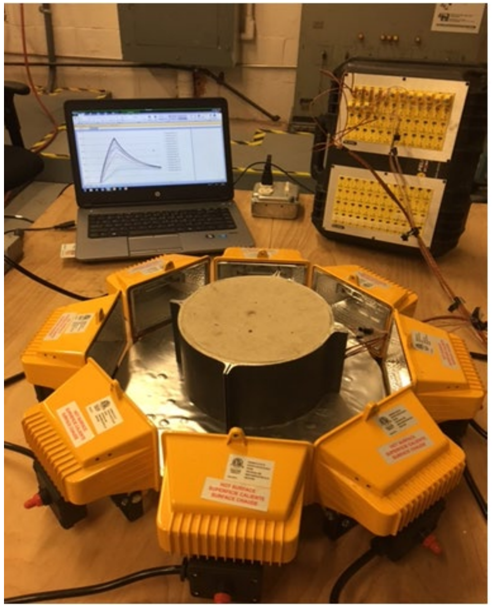
Empty Rocket Motor Casing



Motor Case Filled with Inert Propellant



Full Setup with Instrumentation



- A section of the real motor was used for this test
- Inert propellant simulant was cast into the section
- TCs placed along five thermal paths into the propellant
- TCs placed on outer casing, between case and insulation, between the insulation and the propellant

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Laboratatory Test with 30mm Cartridge in Radiant Chamber in 2022

The cartridge has thermocouples on the interior surface of the case and interior of the projectile.

A wide range of heat fluxes, from slow cook-off to fast cook-off, and beyond are available.

The heating is mostly radiative and very uniform.

Computer models and mitigation schemes could be tested economically and quickly in purpose-built radiant chambers.

The 30mm round shown has six internal thermocouples and recorded temperatures comparable to FCO.

The radiant chamber will be used to to external heat loads to instrument test specimens

Start Up Program Plan

Analysis Phase
Scope problem with analytical solutions
Finite element modeling
Refine model to optimize a point solution for a system of interest

Experimental Data Gathering Phase
Interpret existing FCO data in context of a mitigation scheme
Interpret existing SCO data in context of a mitigation scheme
Interpret hot gun experimental data
Augment hot gun test instrumentation
Attempt 3-D printing of representative mesh
Attempt acoustic alignment
Measure heat flows with and without fibers in radiant chamber

System Concept Development
Select a system of interest with sponsor willingness to participate
Detailed program plan