THE NONEXISTENCE OF GLOBAL SOLUTION FOR SYSTEM OF q-DIFFERENCE INEQUALITIES

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Abstract. In this paper, we obtain sufficient conditions for the nonexistence of global solutions for the system of q-difference inequalities. Our approach is based on the weak formulation of the problem, a particular choice of the test function, and some q-integral inequalities.

1. Introduction. The q-difference calculus or quantum calculus was a classical subject with a long history and wide applications. It was initiated by Jackson [10, 13], and developed by many researchers (see, for example [1, 2, 6, 8, 9, 23]). Several papers on the existence of solutions for different kinds of q-difference equations can be found in the literature (see [11, 12, 14, 24, 3, 4, 5], and the references therein).

The research on the existence of solutions is a meaningful topic, and the study of sufficient conditions for the nonexistence of global solutions to differential equations or inequalities can provide necessary conditions for the existence of solutions. Furthermore, useful information about limit behaviors of many physical systems can be obtained by nonexistence criteria. There are several works in the literature about the nonexistence of solutions for various differential equations or inequalities with nonstandard derivatives. In particular, many researchers have paid much attention to study the absence of solutions for different types of fractional differential problems (such as [21, 19, 20, 22, 17, 18] and the references therein).

In recent years, some results have been obtained on the nonexistence of solutions to q-difference equations and inequalities. For papers on the absence of solutions in quantum calculus, we can refer to [15, 7] and the references therein. Jleli et al. [15] studied the following quantum version of the nonlinear Schrödinger equation

\[ i^q D_{q(t)} u(t, x) + \Delta u(qt, x) = \lambda |u(qt, x)|^p, \quad t > 0, x \in \mathbb{R}^N, \]

where \( 0 < q < 1, i^q \) is the principal value of \( i^q, D_{q(t)} \) is the q-derivative with respect to \( t, \Delta \) is the Laplacian operator in \( \mathbb{R}^N, \lambda \in \mathbb{C} \setminus \{0\}, p > 1, \) and \( u(t, x) \) is a complex-valued function. They obtained the sufficient conditions for the nonexistence of
global weak solution to the considered equation under suitable initial data. Aydi et al. [7] investigated the following $q$-difference inequality

$$(D_qy)(t) \geq |y(qt)|^n, \quad t > 0,$$

subject to the initial condition

$$x(0) = x_0,$$

where $q \in (0, 1)$, $D_q$ is the $q$-derivative operator, $n > 1$, and $y_0 > 0$. They obtained the sufficient conditions for the nonexistence of global solution to the considered $q$-difference inequality under suitable initial data.

In this paper, we consider the nonexistence of global solutions for the system of $q$-difference inequalities

$$
\begin{cases}
(D_qx)(t) \geq |y(qt)|^n \\
(D_qy)(t) \geq |z(qt)|^p \\
(D_qz)(t) \geq |x(qt)|^m
\end{cases}
$$

for $t > 0$, subject to the initial condition

$$x(0) = x_0, \quad y(0) = y_0, \quad z(0) = z_0, \tag{2}$$

where $q \in (0, 1)$, $D_q$ is the $q$-derivative operator, $m > 1$, $n > 1$, $p > 1$, and $x_0 + y_0 + z_0 > 0$.

In the limit case where $q \to 1$, (1) reduces to the following system of ordinary differential inequalities

$$
\begin{cases}
x'(t) \geq |y(qt)|^n \\
y'(t) \geq |z(qt)|^p \\
z'(t) \geq |x(qt)|^m
\end{cases}
$$

for $t > 0$.

In this paper, we obtain sufficient criteria for the absence of global solutions to problems (1)-(2). The proof is based on an extension of the test function method due to Mitidieri and Pohozaev [21] to quantum calculus.

The paper is organized as follows. In Sect. 2, we review some basic concepts on $q$-calculus and present some properties and lemmas that will be used to prove our results. Section 3 is devoted to study the nonexistence of global solutions for problem (1)-(2). In addition, the conclusion can be generalized to $n$-dimension system of $q$-difference inequalities as in Corollary 1.

2. Preliminaries. We denote by $\mathbb{N}$ the set of natural numbers and by $\mathbb{N}^*$ the set $\mathbb{N} \setminus \{0\}$. For convenience of the reader, we recall some basic concepts and lemmas of $q$-calculus theory to facilitate analysis of problem (1)-(2). These details can be found in [8, 23, 16].

Let $q \in (0, 1)$, for $a \in \mathbb{R}$, we define

$$[a]^q = \frac{1 - q^a}{1 - q}.$$  

The $q$-analog of the power $(x - y)^N$ is

$$(x - y)^{(0)} = 1, \quad (x - y)^{(N)} = \prod_{i=0}^{N-1} (x - yq^i), \quad (x, y) \in \mathbb{R}^2, \quad N \in \mathbb{N}.$$  

Let $f : [0, T] \to \mathbb{R}$ ($T > 0$), be a given function such that $f'(t)$ exists in a neighborhood of $t = 0$ and is continuous at $t = 0$. 

The $q$-derivatives of the function $f$ is defined by

$$(D_qf)(t) = \frac{f(t) - f(qt)}{(1 - q)t}, \quad t \in [0, T],$$

$$(D_qf)(0) = f'(0).$$

Notice that if $f$ is differentiable, then

$$\lim_{q \to 1}(D_qf)(t) = f'(t).$$

The $q$-integral of the function $f$ is defined by

$$(I_qf)(t) = \int_0^t f(s)d_q s = (1 - q)t \sum_{n=0}^\infty q^n f(q^n t), \quad t \in [0, T],$$

provided that the sum converges absolutely. We say that $f$ is $q$-integrable on $[0, T]$ if $\int_0^t |f(s)|d_q s < \infty$ for all $t \in [0, T]$. If $f$ is $q$-integrable on $[0, T]$, then

$$\left| \int_0^t f(s)d_q s \right| \leq \int_0^t |f(s)|d_q s, \quad t \in [0, T].$$

Moreover, if $f_1, f_2 : [0, T] \to \mathbb{R}$ are two $q$-integrable functions on $[0, T], T > 0$, then

$$f_1 \leq f_2 \Rightarrow \int_0^T f_1(s)d_q s \leq \int_0^T f_2(s)d_q s.$$ 

By [4], if $f$ is Riemann integrable on $[0, t]$, then

$$\int_0^t f(s)ds = \lim_{q \to 1}(I_qf)(t).$$

**Lemma 2.1.** Let $f \in C([0, \infty); \mathbb{R}), T > 0$, be a continuous function such that $f'(t)$ exists in a neighborhood of $t = 0$ and is continuous at $t = 0$. Then

$$(D_q(I_qf))(t) = f(t), \quad (I_q(D_qf))(t) = f(t) - f(0).$$

Let $u(s) = \alpha s^\beta$, where $0 \leq s \leq t, \alpha > 0$, and $\beta > 0$. Then we have the change-of-variable formula

$$\int_{u(0)}^{u(t)} g(z)d_q z = \int_0^t g(u(s))D_q^{\frac{1}{\beta}} u(s)d_q s,$$

where $g : [0, \alpha s^\beta] \to \mathbb{R}$ is a $q$-integrable function on $[0, \alpha s^\beta]$.

**Lemma 2.2.** Let $N \in \mathbb{N}^+, T > 0$, and $a, b, t \in \mathbb{R}$. Then

$$D_q(a + bt)^{(N)} = N!_q b(a + bt)^{(N-1)},$$

$$\int_0^T (a + bt)^{(N-1)}d_q t = \frac{(a + btq^t)^{(N)} - a^N}{N!_q b q^{N-1}}.$$ 

Next, we recall the following $q$-integration-by-parts rule.

**Lemma 2.3.** Let $f_1, f_2 \in C([0, \infty); \mathbb{R}), T > 0$, be two given functions whose ordinary derivatives exist in a neighborhood of $t = 0$ and are continuous at $t = 0$. Then

$$\int_0^T f_1(s)(D_qf_2)(s)d_q s = [f_1(s)f_2(s)]_{s=0}^T - \int_0^T f_2(qs)(D_qf_1)(s)d_q s.$$
3. Main results.

**Theorem 3.1.** Let $p > 1, m > 1, n > 1$, and $x_0 + y_0 + z_0 > 0$. Then problem (1)-(2) admits no global solutions in $C([0, \infty); \mathbb{R}^3)$.

**Proof of Theorem 3.1.** We argue by contradiction. Suppose that problem (1)-(2) has a global solution $(x, y, z) \in C([0, \infty); \mathbb{R}^3)$. Taking $N \in \mathbb{N}^*$, $0 \leq z \leq 1$ such that
\[
\int_0^1 f_N(z) dz < \infty, \quad \int_0^1 g_N(z) dz < \infty, \quad \int_0^1 h_N(z) dz < \infty, \tag{9}
\]
where
\[
f_N(z) = (1 - z)^{\frac{n}{m-n}} (1 - z)^N, \quad g_N(z) = (1 - z)^{\frac{n}{m-n}} (1 - z)^N, \quad h_N(z) = (1 - z)^{\frac{n}{m-n}} (1 - z)^N. \tag{10}
\]
For an arbitrary $T > 0$, let us introduce the test function
\[
\varphi_T(t) = T^{-N} (T - t)^{(N)}, \quad 0 \leq t \leq T. \tag{11}
\]
Multiplying the first inequality in (1) by $\varphi_T(t)$, using (5), and taking the $q$-integral over $[0, T]$, we obtain
\[
\int_0^T (D_q x)(t) \varphi_T(t) dq t \geq \int_0^T |y(qt)|^p \varphi_T(t) dq t. \tag{12}
\]
Using a $q$-integration by parts (see Lemma 3), we obtain
\[
\int_0^T (D_q x)(t) \varphi_T(t) dq t = [x(t) \varphi_T(t)]_0^T - \int_0^T x(qt) (D_q \varphi_T)(t) dq t.
\]
Using the initial condition $x(0) = x_0$ and the facts that $\varphi_T(T) = 0$ and $\varphi_T(0) = 1$, we get
\[
\int_0^T (D_q x)(t) \varphi_T(t) dq t = -x_0 - \int_0^T x(qt) (D_q \varphi_T)(t) dq t. \tag{13}
\]
Next, by (4),(12) and (13) we obtain
\[
x_0 + \int_0^T |y(qt)|^p \varphi_T(t) dq t
\leq x_0 + \int_0^T (D_q x)(t) \varphi_T(t) dq t
= - \int_0^T x(qt) (D_q \varphi_T)(t) dq t
\leq \left| \int_0^T x(qt) (D_q \varphi_T)(t) dq t \right|
\leq \int_0^T |x(qt)| (D_q \varphi_T)(t) dq t,
\]
that is
\[
x_0 + \int_0^T |y(qt)|^p \varphi_T(t) dq t \leq \int_0^T |x(qt)| (D_q \varphi_T)(t) dq t. \tag{14}
\]
On the other hand, we have
\[ \int_0^T |x(qt)| |(D_q \varphi_T(t))| d_q t = \int_0^T |x(qt)| (\varphi_T(t))^{\frac{m'}{m}} |(D_q \varphi_T(t))| d_q t. \]

Using Young’s inequality, we obtain
\[ \int_0^T |x(qt)| |(D_q \varphi_T(t))| d_q t \leq \frac{1}{m} \int_0^T |x(qt)|^m \varphi_T(t) d_q t + \frac{1}{m'} \int_0^T (\varphi_T(t))^{-\frac{m'}{m}} |(D_q \varphi_T(t))|^m d_q t, \]
where \( \frac{1}{m} + \frac{1}{m'} = 1 \). Therefore, using (14) and (15), we obtain
\[ x_0 + \int_0^T |y(qt)|^m \varphi_T(t) d_q t \leq \frac{1}{m} \int_0^T |x(qt)|^m \varphi_T(t) d_q t + \frac{1}{m'} \int_0^T (\varphi_T(t))^{-\frac{m'}{m}} |(D_q \varphi_T(t))|^m d_q t, \]
By using a similar procedure for the second and third inequality in (1), we have
\[ y_0 + \int_0^T |z(qt)|^p \varphi_T(t) d_q t \leq \frac{1}{p} \int_0^T |y(qt)|^p \varphi_T(t) d_q t + \frac{1}{p'} \int_0^T (\varphi_T(t))^{-\frac{p'}{p}} |(D_q \varphi_T(t))|^p d_q t, \]
where \( \frac{1}{p} + \frac{1}{p'} = 1, \frac{1}{p} + \frac{1}{p'} = 1 \).
Adding (16) and (17) to (18), we obtain
\[ x_0 + y_0 + z_0 + (1 - \frac{1}{m}) \int_0^T |x(qt)|^m \varphi_T(t) d_q t \]
\[ + (1 - \frac{1}{n}) \int_0^T |y(qt)|^n \varphi_T(t) d_q t + (1 - \frac{1}{p}) \int_0^T |z(qt)|^p \varphi_T(t) d_q t \]
\[ \leq \frac{1}{m'} \int_0^T (\varphi_T(t))^{-\frac{m'}{m}} |(D_q \varphi_T(t))|^m d_q t + \frac{1}{n'} \int_0^T (\varphi_T(t))^{-\frac{n'}{n}} |(D_q \varphi_T(t))|^n d_q t \]
\[ + \frac{1}{p'} \int_0^T (\varphi_T(t))^{-\frac{p'}{p}} |(D_q \varphi_T(t))|^p d_q t, \]
which yields
\[ C(x_0 + y_0 + z_0) \]
\[ \leq \int_0^T (\varphi_T(t))^{-\frac{m'}{m}} |(D_q \varphi_T(t))|^m d_q t + \int_0^T (\varphi_T(t))^{-\frac{n'}{n}} |(D_q \varphi_T(t))|^n d_q t \]
\[ + \int_0^T (\varphi_T(t))^{-\frac{p'}{p}} |(D_q \varphi_T(t))|^p d_q t, \]
where \( C = \min\{m', n', p'\} \).
Further, using (7) and (11), we have
\[
(\varphi_T(t))^{-m'} = T^{\frac{N}{m-1}} [(T-t)^{(N)}]^{-\frac{1}{m-1}},
\]
\[
|(D_q\varphi_T)(t)|^{m'} = T^{\frac{Nm}{m-1}} \left( [N]_q \right)^{-\frac{m}{m-1}} [(T - qt)^{(N-1)}]^{\frac{m}{m-1}}.
\]
Hence
\[
\int_0^T (\varphi_T(t))^{-m'} |(D_q\varphi_T)(t)|^{m'} \, dq \, t
= T^{-N} ([N]_q)^{\frac{m}{m-1}} \int_0^T [(T - t)^{(N)}]^{-\frac{m}{m-1}} [(T - qt)^{(N-1)}]^{\frac{m}{m-1}} dq \, t.
\] (20)

Next, we obtain
\[
[(T - t)^{(N)}]^{-\frac{m}{m-1}} [(T - qt)^{(N-1)}]^{\frac{m}{m-1}}
= \prod_{i=0}^{N-2} (T - q^{i+1}t)^{\frac{m}{m-1}}
\]
\[
= \frac{1}{(T-t)^{\frac{m}{m-1}}} \prod_{i=1}^{N-1} (T - q^i t)^{\frac{m}{m-1}}
\]
\[
= \frac{1}{(T-t)^{\frac{m}{m-1}}} \prod_{i=1}^{N-1} (T - q^i t)
\]
\[
= \frac{T^{N-1}}{(T-t)^{\frac{m}{m-1}}} \prod_{i=1}^{N-1} \left( T - q^i t \right)
\]
\[
= \frac{T^{N-1}}{(T-t)^{\frac{m}{m-1}}} \left( \prod_{i=0}^{N-1} \left( 1 - q^i t \right) \right)^{(N)}
\]
\[
= T^{N-\frac{m}{m-1}} \left( 1 - t \frac{T}{T} \right)^{-\frac{m}{m-1}} \left( 1 - t \frac{T}{T} \right)^{(N)}.
\]

Therefore, from (20), we obtain
\[
\int_0^T (\varphi_T(t))^{-m'} |(D_q\varphi_T)(t)|^{m'} \, dq \, t
= ([N]_q)^{\frac{m}{m-1}} T^{\frac{m}{m-1}} \int_0^T \left( 1 - t \frac{T}{T} \right)^{-\frac{m}{m-1}} \left( 1 - t \frac{T}{T} \right)^{(N)} \, dq \, t
= ([N]_q)^{\frac{m}{m-1}} T^{\frac{m}{m-1} + 1} \int_0^T f_N((u(t)) (D_q^u)(t)) d_q \, t,
\]
where \( u(t) = \frac{t}{T}, \) \( 0 \leq t \leq T, \) and \( f_N \) is defined by (10). Using the change-of-variable formula (6), we get

\[
\int_0^T (\varphi_T(t))^{-\frac{m}{m-1}} |(D_q \varphi_T)(t)|^{m'} d_q t = ([N]_q)^{\frac{m}{m-1}} T^{\frac{m}{m-1}} \int_0^1 f_N(z) d_q z.
\]

Similarly, we obtain

\[
\int_0^T (\varphi_T(t))^{-\frac{n}{n-1}} |(D_q \varphi_T)(t)|^{n'} d_q t = ([N]_q)^{\frac{n}{n-1}} T^{\frac{n}{n-1}} \int_0^1 g_N(z) d_q z,
\]

\[
\int_0^T (\varphi_T(t))^{-\frac{p}{p-1}} |(D_q \varphi_T)(t)|^{p'} d_q t = ([N]_q)^{\frac{p}{p-1}} T^{\frac{p}{p-1}} \int_0^1 h_N(z) d_q z.
\]

Therefore, from (19), we obtain

\[
C(x_0 + y_0 + z_0) \
\leq ([N]_q)^{\frac{m}{m-1}} T^{\frac{m}{m-1}} \int_0^1 f_N(z) d_q z + ([N]_q)^{\frac{n}{n-1}} T^{\frac{n}{n-1}} \int_0^1 g_N(z) d_q z \
+ ([N]_q)^{\frac{p}{p-1}} T^{\frac{p}{p-1}} \int_0^1 h_N(z) d_q z.
\]

Recall that from (10) we have \( \int_0^1 f_N(z) d_q z < \infty, \int_0^1 g_N(z) d_q z < \infty, \int_0^1 h_N(z) d_q z < \infty. \) Since this inequality holds for every \( T > 0, \) passing to the limit as \( T \to \infty, \) we obtain \( x_0 + y_0 + z_0 \leq 0, \) which contradicts the fact that \( x_0 + y_0 + z_0 > 0. \) The obtained contradiction implies the nonexistence of a global solution to (1)-(2) for any \( m, n, p > 1. \)

By using similar procedure in Theorem 1, the conclusion can be generalized to \( n \)-dimension system of \( q \)-difference inequalities.

**Corollary 1.** Consider the following system of \( q \)-difference inequalities

\[
\begin{align*}
(D_q x_1)(t) & \geq |x_2(qt)|^{m_2} \\
(D_q x_2)(t) & \geq |x_3(qt)|^{m_3} \\
& \quad \cdots \\
(D_q x_{n-1})(t) & \geq |x_n(qt)|^{m_n} \\
(D_q x_n)(t) & \geq |x_1(qt)|^{m_1}
\end{align*}
\]

for \( t > 0, \) subject to the initial condition

\[ x_i(0) = x_0^i, \quad i = 1, 2 \cdots , n. \quad (22) \]

If \( m_i > 1 (i = 1, 2 \cdots , n), \) and \( \sum_{i=1}^n x_0^i > 0, \) then problem (21)-(22) admits no global solutions in \( C([0, \infty); \mathbb{R}^n). \)

4. **Conclusion.** In this paper, we obtain sufficient conditions for the nonexistence of global solutions for the system of \( q \)-difference inequalities. The proof is based on a particular choice of the test function and some known results in the lemmas. Inspired by [7], by selecting one more special function in the proof, we generalize the system of \( q \)-difference inequalities from two-dimension to three-dimension. In
addition, the conclusion can be generalized to the situation of $n$-dimension system of $q$-difference inequalities by selecting $n$ special functions. Based on our work and some references, such as [19, 20, 22, 17, 18], we will continue to study the existence of solutions for system of different $q$-difference inequalities or other fractional differential inequalities.

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