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A new note on generalized absolute matrix summability

HS Özarslan* and T Ari

*Correspondence:
seyhan@erciyes.edu.tr
Department of Mathematics, Erciyes University, Kayseri, 38039, Turkey

Abstract

This paper gives necessary and sufficient conditions in order that a series $\sum a_n\lambda_n$ should be summable $|B|_k$, $k \geq 1$, whenever $\sum a_n$ is summable $|A|$. Some new results have also been obtained.

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1 Introduction

Let $\sum a_n$ be a given infinite series with the partial sums (s_n). Let (p_n) be a sequence of positive numbers such that

$$P_n = \sum_{v=0}^{n} p_v \to \infty \quad \text{as } (n \to \infty), \qquad (P_{-i} = p_{-i} = 0, i \geq 1). \tag{1}$$

The sequence-to-sequence transformation

$$t_n = \frac{1}{P_n} \sum_{v=0}^{n} p_v s_v \tag{2}$$

defines the sequence (t_n) of the Riesz means of the sequence (s_n) generated by the sequence of coefficients (p_n) (see [3]). The series $\sum a_n$ is said to be summable $|R, p_n|_k$, $k \geq 1$, if (see [1])

$$\sum_{n=1}^{\infty} n^{k-1} |t_n - t_{n-1}|^k < \infty. \tag{3}$$

Let $A = (a_{nv})$ be a normal matrix, *i.e.*, a lower triangular matrix of nonzero diagonal entries. Then A defines the sequence-to-sequence transformation, mapping the sequence $s = (s_n)$ to $As = (A_n(s))$, where

$$A_n(s) = \sum_{v=0}^{n} a_{nv} s_v, \quad n = 0, 1, \ldots. \tag{4}$$

The series $\sum a_n$ is said to be summable $|A|_k$, $k \geq 1$, if (see [7])

$$\sum_{n=1}^{\infty} n^{k-1} \left| \bar{\Delta} A_n(s) \right|^k < \infty, \tag{5}$$

where

$$\bar{\Delta} A_n(s) = A_n(s) - A_{n-1}(s).$$

If we take $a_{nv} = \frac{p_v}{P_n}$, then $|A|_k$ summability is the same as $|R, p_n|_k$ summability.

Before stating the main theorem we must first introduce some further notations.

Given a normal matrix $A = (a_{nv})$, we associate two lover semimatrices $\bar{A} = (\bar{a}_{nv})$ and $\hat{A} = (\hat{a}_{nv})$ as follows:

$$\bar{a}_{nv} = \sum_{i=v}^{n} a_{ni}, \quad n, v = 0, 1, \ldots \tag{6}$$

and

$$\hat{a}_{00} = \bar{a}_{00} = a_{00}, \qquad \hat{a}_{nv} = \bar{a}_{nv} - \bar{a}_{n-1,v}, \quad n = 1, 2, \ldots. \tag{7}$$

It may be noted that $\bar{A}$ and $\hat{A}$ are the well-known matrices of series-to-sequence and series-to-series transformations, respectively. Then, we have

$$A_n(s) = \sum_{v=0}^{n} a_{nv} s_v = \sum_{v=0}^{n} \bar{a}_{nv} a_v \tag{8}$$

and

$$\bar{\Delta} A_n(s) = \sum_{v=0}^{n} \hat{a}_{nv} a_v. \tag{9}$$

If A is a normal matrix, then $A' = (a'_{nv})$ will denote the inverse of A. Clearly if A is normal, then $\hat{A} = (\hat{a}_{nv})$ is normal and has two-sided inverse $\hat{A}' = (\hat{a}'_{nv})$, which is also normal (see [2]).

Sarıgöl [6] has proved the following theorem for $|R, p_n|_k$ summability method.

Theorem A *Suppose that (p_n) and (q_n) are positive sequences with $P_n \to \infty$ and $Q_n \to \infty$ as $n \to \infty$. Then $\sum a_n \lambda_n$ is summable $|R, q_n|_k$, $k \geq 1$ whenever $\sum a_n$ is summable $|R, p_n|$, if and only if*

$$\lambda_n = O\left\{ n^{\frac{1}{k}-1} \frac{q_n P_n}{p_n Q_n} \right\}, \tag{10}$$

$$W_n \Delta(Q_{n-1}\lambda_n) = O\left(\frac{p_n}{P_n} \right), \tag{11}$$

$$Q_n \lambda_{n+1} W_n = O(1) \tag{12}$$

provided that

$$W_n = \left\{ \sum_{v=n+1}^{\infty} v^{k-1} \left(\frac{q_v}{Q_v Q_{v-1}} \right)^k \right\}^{\frac{1}{k}} < \infty.$$

Theorem B *The $|R, p_n|$ summability implies the $|R, q_n|_k$, $k \geq 1$, summability if and only if the following conditions hold:*

$$\frac{q_v}{Q_v} \cdot \frac{P_v}{p_v} = O\left\{ v^{\frac{1}{k}-1} \right\}, \tag{13}$$

$$|\Delta Q_{v-1}| \cdot W_v = O\left(\frac{p_v}{P_v} \right), \tag{14}$$

$$Q_v W_v = O(1), \tag{15}$$

where

$$W_v = \left\{ \sum_{i=v+1}^{\infty} i^{k-1} \left(\frac{q_i}{Q_i Q_{i-1}} \right)^k \right\}^{\frac{1}{k}} < \infty$$

and we regarded that the above series converges for each v and Δ is the forward difference operator.

It may be remarked that the above theorem has been proved by Orhan and Sarıgöl [5].

Lemma ([4]) *$A = (a_{nv}) \in (l_1, l_k)$ if and only if*

$$\sup_v \sum_{n=1}^{\infty} |a_{nv}|^k < \infty \tag{16}$$

for the cases $1 \leq k < \infty$, where (l_1, l_k) denotes the set of all matrices A which map l_1 into $l_k = \{x = (x_n) : \sum |x_n|^k < \infty\}$.

2 Main theorem

The aim of this paper is to generalize Theorem A for the $|A|$ and $|B|_k$ summabilities. Therefore we shall prove the following theorem.

Theorem *Let $k \geq 1$, $A = (a_{nv})$ and $B = (b_{nv})$ be two positive normal matrices such that*

$$a_{n-1,v} \geq a_{nv}, \quad \text{for } n \geq v+1, \tag{17}$$

$$\bar{a}_{n0} = 1, \quad n = 0, 1, 2, \ldots. \tag{18}$$

Then, in order that $\sum a_n \lambda_n$ is summable $|B|_k$ whenever $\sum a_n$ is summable $|A|$, it is necessary that

$$|\lambda_n| = O\left(n^{\frac{1}{k}-1} \frac{a_{nn}}{b_{nn}} \right), \tag{19}$$

$$\sum_{n=v+1}^{\infty} n^{k-1}\left|\Delta_v(\hat{b}_{nv}\lambda_v)\right|^k = O\left(a_{vv}^k\right), \tag{20}$$

$$\sum_{n=v+1}^{\infty} n^{k-1}|\hat{b}_{n,v+1}\lambda_{v+1}|^k = O(1). \tag{21}$$

Also (19)-(21) and

$$\bar{b}_{n0} = 1, \quad n = 0,1,2,\ldots, \tag{22}$$

$$a_{nn} - a_{n+1,n} = O(a_{nn}a_{n+1,n+1}), \tag{23}$$

$$\sum_{v=r+2}^{\infty} \left|\hat{b}_{nv}\hat{a}'_{vr}\lambda_v\right| = O\left(|\hat{b}_{n,r+1}\lambda_{r+1}|\right) \tag{24}$$

are sufficient for the consequent to hold.

It should be noted that if we take $a_{nv} = \frac{p_v}{P_n}$ and $b_{nv} = \frac{q_v}{Q_n}$, then we get Theorem A. Also if we take $\lambda_n = 1$, then we get Theorem B.

Proof of the Theorem

Necessity. Let (x_n) and (y_n) denote A-transform and B-transform of the series $\sum a_n$ and $\sum a_n\lambda_n$, respectively. Then, by (8) and (9), we have

$$\bar{\Delta}x_n = \sum_{v=0}^{n} \hat{a}_{nv}a_v \quad \text{and} \quad \bar{\Delta}y_n = \sum_{v=0}^{n} \hat{b}_{nv}a_v\lambda_v. \tag{25}$$

For $k \geq 1$, we define

$$A = \left\{(a_i) : \sum a_i \text{ is summable } |A|\right\}, \qquad B = \left\{(a_i\lambda_i) : \sum a_i\lambda_i \text{ is summable } |B|_k\right\}.$$

Then it is routine to verify that these are BK-spaces, if normed by

$$\|X\| = \left\{\sum_{n=0}^{\infty} |\bar{\Delta}x_n|\right\} \tag{26}$$

and

$$\|Y\| = \left\{\sum_{n=0}^{\infty} n^{k-1}|\bar{\Delta}y_n|^k\right\}^{\frac{1}{k}} \tag{27}$$

respectively. Since $\sum a_n$ is summable $|A|$ implies $\sum a_n\lambda_n$ is summable $|B|_k$, by the hypothesis of the theorem,

$$\|X\| < \infty \quad \Rightarrow \quad \|Y\| < \infty.$$

Now consider the inclusion map $c : A \to B$ defined by $c(x) = x$. This is continuous, which is immediate as A and B are BK-spaces. Thus there exists a constant M such that

$$\|Y\| \leq M\|X\|. \tag{28}$$

By applying (25) to $a_\nu = e_\nu - e_{\nu+1}$ (e_ν is the νth coordinate vector), we have

$$\bar{\Delta}x_n = \begin{cases} 0, & \text{if } n < \nu, \\ \hat{a}_{n\nu}, & \text{if } n = \nu, \\ \Delta_\nu \hat{a}_{n\nu}, & \text{if } n > \nu \end{cases}$$

and

$$\bar{\Delta}y_n = \begin{cases} 0, & \text{if } n < \nu, \\ \hat{b}_{n\nu}\lambda_\nu, & \text{if } n = \nu, \\ \Delta_\nu(\hat{b}_{n\nu}\lambda_\nu), & \text{if } n > \nu. \end{cases}$$

So (26) and (27) give us

$$\|X\| = \left\{ a_{\nu\nu} + \sum_{n=\nu+1}^{\infty} |\Delta_\nu \hat{a}_{n\nu}| \right\}$$

and

$$\|Y\| = \left\{ \nu^{k-1} b_{\nu\nu}|\lambda_\nu|^k + \sum_{n=\nu+1}^{\infty} n^{k-1} \bigl|\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)\bigr|^k \right\}^{\frac{1}{k}}.$$

Hence it follows from (28) that

$$\nu^{k-1} b_{\nu\nu}|\lambda_\nu|^k + \sum_{n=\nu+1}^{\infty} n^{k-1} |\Delta_\nu \hat{b}_{n\nu}\lambda_\nu|^k \le M^k a_{\nu\nu}^k + M^k \sum_{n=\nu+1}^{\infty} |\Delta_\nu \hat{a}_{n\nu}|^k.$$

Using (17), we can find

$$\nu^{k-1} b_{\nu\nu}|\lambda_\nu|^k + \sum_{n=\nu+1}^{\infty} n^{k-1} \bigl|\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)\bigr|^k = O\bigl(a_{\nu\nu}^k\bigr).$$

The above inequality will be true if and only if each term on the left-hand side is $O(a_{\nu\nu}^k)$. Taking the first term,

$$\nu^{k-1} b_{\nu\nu}|\lambda_\nu|^k = O\bigl(a_{\nu\nu}^k\bigr)$$

then

$$|\lambda_\nu| = O\left(\nu^{\frac{1}{k}-1} \frac{a_{\nu\nu}}{b_{\nu\nu}} \right)$$

which verifies that (19) is necessary. Using the second term, we have

$$\sum_{n=\nu+1}^{\infty} n^{k-1} \bigl|\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)\bigr|^k = O\bigl(a_{\nu\nu}^k\bigr)$$

which is condition (20). Now, if we apply (22) to $a_\nu = e_{\nu+1}$, we have

$$\bar{\Delta} x_n = \begin{cases} 0, & \text{if } n \le \nu, \\ \hat{a}_{n,\nu+1}, & \text{if } n > \nu \end{cases}$$

and

$$\bar{\Delta} y_n = \begin{cases} 0, & \text{if } n \le \nu, \\ \hat{b}_{n,\nu+1}\lambda_{\nu+1}, & \text{if } n > \nu, \end{cases}$$

respectively. Hence

$$\|X\| = \left\{ \sum_{n=\nu+1}^{\infty} |\hat{a}_{n,\nu+1}| \right\},$$

$$\|Y\| = \left\{ \sum_{n=\nu+1}^{\infty} n^{k-1} |\hat{b}_{n,\nu+1}\lambda_{\nu+1}|^k \right\}^{\frac{1}{k}}.$$

Hence it follows from (28) that

$$\sum_{n=\nu+1}^{\infty} n^{k-1} |\hat{b}_{n,\nu+1}\lambda_{\nu+1}|^k \le M^k \left\{ \sum_{n=\nu+1}^{\infty} |\hat{a}_{n,\nu+1}| \right\}^k.$$

Using (18) we can find

$$\sum_{n=\nu+1}^{\infty} n^{k-1} |\hat{b}_{n,\nu+1}\lambda_{\nu+1}|^k = O(1)$$

which is condition (21).

Sufficiency. We use the notations of necessity. Then

$$\bar{\Delta} x_n = \sum_{\nu=0}^{n} \hat{a}_{n\nu} a_\nu \tag{29}$$

which implies

$$a_\nu = \sum_{r=0}^{\nu} \hat{a}'_{\nu r} \bar{\Delta} x_r. \tag{30}$$

In this case

$$\bar{\Delta} y_n = \sum_{\nu=0}^{n} \hat{b}_{n\nu} a_\nu \lambda_\nu = \sum_{\nu=0}^{n} \hat{b}_{n\nu}\lambda_\nu \sum_{r=0}^{\nu} \hat{a}'_{\nu r} \bar{\Delta} x_r.$$

On the other hand, since

$$\hat{b}_{n0} = \bar{b}_{n0} - \bar{b}_{n-1,0}$$

by (22), we have

$$\begin{aligned}\bar{\Delta} y_n &= \sum_{\nu=1}^{n} \hat{b}_{n\nu}\lambda_\nu \left\{ \sum_{r=0}^{\nu} \hat{a}'_{\nu r}\bar{\Delta} x_r \right\} \\ &= \sum_{\nu=1}^{n} \hat{b}_{n\nu}\lambda_\nu \left\{ \hat{a}'_{\nu\nu}\bar{\Delta} x_\nu + \hat{a}'_{\nu,\nu-1}\bar{\Delta} x_{\nu-1} + \sum_{r=0}^{\nu-2} \hat{a}'_{\nu r}\bar{\Delta} x_r \right\} \\ &= \sum_{\nu=1}^{n} \hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu\nu}\bar{\Delta} x_\nu + \sum_{\nu=1}^{n} \hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu,\nu-1}\bar{\Delta} x_{\nu-1} + \sum_{\nu=1}^{n} \hat{b}_{n\nu}\lambda_\nu \sum_{r=0}^{\nu-2} \hat{a}'_{\nu r}\bar{\Delta} x_r \\ &= \hat{b}_{nn}\lambda_n \hat{a}'_{nn}\bar{\Delta} x_n + \sum_{\nu=1}^{n-1} \big(\hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu\nu} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\hat{a}'_{\nu+1,\nu} \big) \bar{\Delta} x_\nu \\ &\quad + \sum_{r=0}^{n-2} \bar{\Delta} x_r \sum_{\nu=r+2}^{n} \hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu r}. \end{aligned} \tag{31}$$

By considering the equality

$$\sum_{k=\nu}^{n} \hat{a}'_{nk}\hat{a}_{k\nu} = \delta_{n\nu},$$

where $\delta_{n\nu}$ is the Kronecker delta, we have that

$$\begin{aligned}\hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu\nu} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\hat{a}'_{\nu+1,\nu} &= \frac{\hat{b}_{n\nu}\lambda_\nu}{\hat{a}_{\nu\nu}} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\left(-\frac{\hat{a}_{\nu+1,\nu}}{\hat{a}_{\nu\nu}\hat{a}_{\nu+1,\nu+1}} \right) \\ &= \frac{\hat{b}_{n\nu}\lambda_\nu}{a_{\nu\nu}} - \frac{\hat{b}_{n,\nu+1}\lambda_{\nu+1}(\bar{a}_{\nu+1,\nu} - \bar{a}_{\nu,\nu})}{a_{\nu\nu}a_{\nu+1,\nu+1}} \\ &= \frac{\hat{b}_{n\nu}\lambda_\nu}{a_{\nu\nu}} - \frac{\hat{b}_{n,\nu+1}\lambda_{\nu+1}(a_{\nu+1,\nu+1} + a_{\nu+1,\nu} - a_{\nu\nu})}{a_{\nu\nu}a_{\nu+1,\nu+1}} \\ &= \frac{\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)}{a_{\nu\nu}} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\frac{a_{\nu\nu} - a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}} \end{aligned}$$

and so

$$\begin{aligned}\bar{\Delta} y_n &= \frac{b_{nn}\lambda_n}{a_{nn}}\bar{\Delta} x_n + \sum_{\nu=1}^{n-1} \frac{\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)}{a_{\nu\nu}}\bar{\Delta} x_\nu + \sum_{\nu=1}^{n-1} \hat{b}_{n,\nu+1}\lambda_{\nu+1}\frac{a_{\nu\nu} - a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}}\bar{\Delta} x_\nu \\ &\quad + \sum_{r=0}^{n-2} \bar{\Delta} x_r \sum_{\nu=r+2}^{n} \hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu r}. \end{aligned}$$

Let

$$T_n(1) = \frac{b_{nn}\lambda_n}{a_{nn}}\bar{\Delta} x_n + \sum_{\nu=1}^{n-1} \frac{\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)}{a_{\nu\nu}}\bar{\Delta} x_\nu + \sum_{\nu=1}^{n-1} \hat{b}_{n,\nu+1}\lambda_{\nu+1}\frac{a_{\nu\nu} - a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}}\bar{\Delta} x_\nu,$$

$$T_n(2) = \sum_{r=0}^{n-2} \bar{\Delta} x_r \sum_{\nu=r+2}^{n} \hat{b}_{n\nu}\lambda_\nu \hat{a}'_{\nu r}.$$

Since

$$\left|T_n(1)+T_n(2)\right|^k \le 2^k\left(\left|T_n(1)\right|^k+\left|T_n(2)\right|^k\right)$$

to complete the proof of Theorem, it is sufficient to show that

$$\sum_{n=1}^{\infty} n^{k-1}\left|T_n(i)\right|^k < \infty \quad \text{for } i=1,2.$$

Then

$$\begin{aligned}\overline{T_n(1)} &= n^{1-\frac{1}{k}} T_n(1)\\ &= n^{1-\frac{1}{k}} \frac{b_{nn}\lambda_n}{a_{nn}} \bar{\Delta} x_n + n^{1-\frac{1}{k}} \sum_{\nu=1}^{n-1} \frac{\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)}{a_{\nu\nu}} \bar{\Delta} x_\nu + n^{1-\frac{1}{k}} \sum_{\nu=1}^{n-1} \hat{b}_{n,\nu+1}\lambda_{\nu+1} \frac{a_{\nu\nu}-a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}} \bar{\Delta} x_\nu\\ &= \sum_{\nu=1}^{\infty} c_{n\nu} \bar{\Delta} x_\nu,\end{aligned}$$

where

$$c_{n\nu} = \begin{cases} n^{1-\frac{1}{k}}\left(\frac{\Delta_\nu(b_{n\nu}\lambda_\nu)}{a_{\nu\nu}} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\frac{a_{\nu\nu}-a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}}\right), & \text{if } 1 \le \nu \le n-1,\\ n^{1-\frac{1}{k}} \frac{b_{nn}\lambda_n}{a_{nn}}, & \text{if } \nu = n,\\ 0, & \text{if } \nu > n.\end{cases}$$

Now

$$\sum \left|\overline{T_n(1)}\right|^k < \infty \quad \text{whenever } \sum |\bar{\Delta} x_n| < \infty$$

is equivalently

$$\sup_\nu \sum_{n=1}^{\infty} |c_{n\nu}|^k < \infty \tag{32}$$

by Lemma. But it follows from conditions (20), (21) and (23) that

$$\begin{aligned}\sum_{n=\nu}^{\infty} |c_{n\nu}|^k &= O(1)\left\{n^{k-1}\left|\frac{b_{nn}\lambda_n}{a_{nn}}\right|^k + \sum_{n=\nu+1}^{\infty} n^{k-1}\left|\frac{\Delta_\nu(\hat{b}_{n\nu}\lambda_\nu)}{a_{\nu\nu}} + \hat{b}_{n,\nu+1}\lambda_{\nu+1}\frac{a_{\nu\nu}-a_{\nu+1,\nu}}{a_{\nu\nu}a_{\nu+1,\nu+1}}\right|^k\right\}\\ &= O(1) \quad \text{as } \nu \to \infty.\end{aligned}$$

Finally,

$$\overline{T_n(2)} = n^{1-\frac{1}{k}} T_n(2) = n^{1-\frac{1}{k}} \sum_{r=0}^{n-2} \bar{\Delta} x_r \sum_{\nu=r+2}^{n} \hat{b}_{n\nu}\hat{a}'_{\nu r}\lambda_\nu = \sum_{r=0}^{\infty} d_{nr} \bar{\Delta} x_r,$$

where

$$d_{nr} = \begin{cases} n^{1-\frac{1}{k}} \sum_{\nu=r+2}^{n} \hat{b}_{n\nu}\hat{a}'_{\nu r}\lambda_\nu, & \text{if } 0 \le r \le n-2,\\ 0, & \text{if } r > n-2.\end{cases}$$

Now

$$\sum \left|\overline{T_n(2)}\right|^k < \infty \quad \text{whenever } \sum |\bar{\Delta} x_n| < \infty$$

is equivalently

$$\sup_r \sum_{n=1}^{\infty} |d_{nr}|^k < \infty \tag{33}$$

by Lemma. But it follows from conditions (21) and (24) that

$$\begin{aligned} \sum_{n=r+2}^{\infty} |d_{nr}|^k &= O(1) \sum_{n=r+2}^{\infty} n^{k-1} \left\{ \sum_{v=r+2}^{\infty} \left| \hat{b}_{nv} \hat{a}'_{vr} \lambda_v \right| \right\}^k \\ &= O(1) \sum_{n=r+2}^{\infty} n^{k-1} |\hat{b}_{n,r+1} \lambda_{r+1}|^k \\ &= O(1) \quad \text{as } r \to \infty. \end{aligned}$$

Therefore, we have

$$\sum_{n=1}^{\infty} n^{k-1} \left|T_n(i)\right|^k < \infty \quad \text{for } i = 1, 2.$$

This completes the proof of the Theorem. □

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